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Appendix A: Benefits of Reducing Demand for Gasoline and Diesel (Task 1)

CONSULTANT REPORT

September 2003
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Gray Davis, *Governor*

CALIFORNIA ENERGY COMMISSION

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Benefits of Reducing Demand for Gasoline and Diesel

Contractor Report

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1. Introduction

California's ever-increasing consumption of petroleum products in the face of limited refining capacity and less secure sources of crude oil exposes our economy to great risk. If measures are implemented in the near future to both reduce demand and augment supply, the risk to our economy can be mitigated.

Assembly Bill 2076 (Chapter 936, Statutes of 2000) requires the California Energy Commission and the California Air Resources Board (ARB) to develop and submit a strategy to the Legislature to reduce petroleum dependence in California. The statute requires the strategy to include goals for reducing the rate of growth in the demand for petroleum fuels. Options to be considered include increasing transportation energy efficiency, as well as using non-petroleum fuels and advanced transportation technologies including alternative-fueled vehicles and hybrid vehicles.

The California Energy Commission and the ARB have developed a program and methodologies to evaluate and analyze possible petroleum reduction options. The goal of this effort is to provide policy makers with a robust analysis of the possible measures that could be implemented to meet the fuel demands of consumers and industry. This analysis needs to account for the costs of these measures as well as the benefits. The overall effort is guided by consultant services provided by Acurex Environmental, a TIAX LLC (TIAX) company.

This work has been divided into several tasks and assigned to the California Energy Commission and ARB staffs.

- The ARB leads Task 1 to determine the possible benefits of reducing the demand for gasoline and diesel fuel in California. The focus of this report is to determine the direct environmental net benefit (DENB) — the dollar value of a net reduction in air emissions and multimedia impacts. This report also quantifies the reduction in the external costs of petroleum dependency — those costs associated with petroleum use, including economic impact of price spikes, and other externalities — resulting from a reduction in petroleum consumption.

- The California Energy Commission leads Task 2 to determine the future demand for refined products, especially gasoline and diesel fuels. The results of this task are contained in a report entitled *Base Case Forecast of California Transportation Energy Demand*, published December 2001 (Energy Commission 2001). In this report, the California Energy Commission projected total personal income, population, vehicle miles traveled, and demand for gasoline and diesel fuels.

- The California Energy Commission also leads Task 3, which assesses possible options to reduce petroleum dependency and the level of petroleum consumption. The direct non-environmental net benefits (DNNB) are determined in this report.

- The California Energy Commission and the ARB will jointly lead Task 4, which provides integration of the results of Tasks 1, 2, and 3. They will develop strategies and provide recommendations to stakeholders for discussion. Alternative strategies may also be developed and presented to the California Energy Commission and ARB. Recommendations for establishing statewide petroleum reduction goals and possible policies to achieve these goals will be considered for adoption and presented to the Governor and Legislature.

The purpose of this report is to assess the DENB and the impact on the external costs of petroleum dependency in California between 2002 and 2030 for all of the options considered. The methodologies employed for these assessments are described in Sections 1.1 and 1.2, respectively.

1.1 Direct Environmental Net Benefit Analysis Methodology

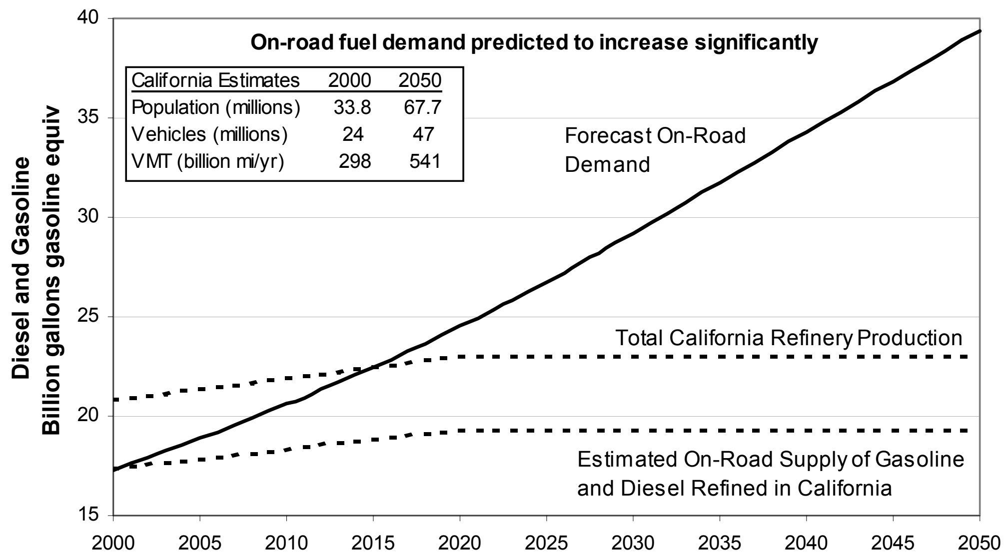
In order to determine the DENB of a particular petroleum reduction option, three major categories of environmental impacts were considered: criteria air pollutant emissions, greenhouse gas (GHG) emissions, and ground and water impacts. For simplification, this analysis considers only the local (i.e., in-state) changes in criteria pollutants or ground and water impacts associated with a given petroleum reduction option. Criteria pollutant emissions and ground and water impacts that take place out-of-state are excluded from this analysis, even though they may have resulted from petroleum reduction within California.

Unlike criteria pollutants and ground and water pollution, the benefits of reducing GHG emissions are global. For this reason, when environmental impacts are counted for a given petroleum reduction option, GHG emissions are counted for every step of the fuel life cycle — from feedstock extraction to the tailpipe of a vehicle in California — regardless of where the steps in between take place. In contrast, criteria pollutants and ground and water impacts are tracked from the point where a given fuel stream enters California boundaries to the point of use.

As part of the DENB analysis, in-state environmental impacts associated with fuel use and production were calculated for vehicles operating in the South Coast Air Basin (SoCAB). In order to extend these results to all California vehicles participating in petroleum reduction options, we assumed that most California vehicles participating in petroleum reduction options would operate in high population density urban and suburban regions like the SoCAB. We also assumed that environmental impacts associated with SoCAB vehicles resemble the environmental impacts associated with vehicles operating in other in-state urban and suburban regions. Based on these assumptions, we assumed that the environmental impact analysis results for SoCAB vehicles were applicable to all in-state vehicles participating in future petroleum reduction options. A more complete definition of the fuel life cycle and related assumptions are given in Section 2.1.

1.1.1 Petroleum Reduction Options Assessed in this Study

As shown in Figure 1-1, gasoline and diesel demand is expected to double by 2030 while supply from California refineries is expected to remain relatively flat[1].



A small expansion of California refinery capacity is projected through 2020, as refineries continue to upgrade equipment and processes. The estimated expansion is 0.5 percent per year (Stillwater 2002). Refinery expansion is discussed further in Section 2.

Figure 1-1. California Refinery Output Will Not Meet Growing Gasoline Demand

Given that the state gasoline and diesel demand is expected to exceed state refinery production in future years, this analysis considers the following possible means for meeting future gasoline and diesel — and hence, petroleum — demand:

- Reducing petroleum demand through increased vehicle fuel efficiency and/or reduced vehicle use
- Avoiding petroleum use by using alternative-fuel vehicles in place of conventional-fuel vehicles
- Importing refined petroleum products from other states and/or from outside the U.S. in order to meet the growing fuel demand

For this analysis, we assumed that petroleum displacement measures will not bring state fuel demand below current state refinery capacity prior to 2020. Further, we assumed that if state fuel demand were reduced below state refinery capacity, refineries would continue to produce at capacity. With this in mind, any measure to reduce future petroleum demand will impact out-of-state fuel import volumes or in-state export volumes, not in-state production volumes, as there will be ample demand for state refineries to produce at full capacity.

[1] See discussion of petroleum fuels in Section 2. Diesel and LPG production from California refineries is also expected to remain relatively flat. The emission impact of displacing a very large fraction of in-state refinery capacity with alternative fuels is not analyzed here as it is assumed that increased alternative fuel use would displace out-of-state conventional fuel imports.

The environmental impacts due to an incremental change of petroleum fuel use were determined for a variety of petroleum reduction options. These options have been divided into the four categories shown in Table 1-1.

Table 1-1. Options Assessed for Reducing Petroleum Consumption

Group 1 — Fuel Efficiency Options[a]
Improved Vehicle Fuel Economy Fuel-Efficient Replacement Tires and Tire Inflation Efficient Vehicles in Government Fleets Vehicle Maintenance Practices High Efficiency Heavy-duty Vehicles (HDVs) and Medium-duty Vehicles (MDVs) using Diesel
Group 2 — Fuel Displacement Options[b]
Fuel Cell Vehicles (FCVs): Gasoline, Hydrogen, and Methanol Battery Electric Vehicles (EVs) Grid-Connected Hybrid Vehicles Compressed Natural Gas (CNG) for Light-duty Vehicles (LDVs) High Efficiency Diesel LDVs Liquefied Petroleum Gas (LPG) Alcohol Fuels in Flexible Fuel LDVs Ethanol as a Gasoline Blending Component LNG and Advanced CNG Engines for HDVs and MDVs Fischer-Tropsch Diesel (FTD) – gas to liquid fuels Biodiesel as a Diesel Blending Component
Group 3 — Pricing Options[c]
Higher Gasoline Tax Pay-at-the-Pump and Pay-as-you-Drive Auto Insurance Tax on Vehicles Miles Traveled (VMT) Registration Fee Transfer Purchase Incentives for Efficient Vehicles Feebates
Group 4 — Other Options[d]
Expanded Use of Public Transit Land Use Planning Telecommuting Reducing Speed Limits Voluntary Accelerated Vehicle Retirement

[a]Group 1 involves options that improve vehicle fuel efficiency, but do not change the total vehicle miles traveled (VMT) or require the use of an alternative fuel.
[b]Group 2 involves options that replace conventional fuel consumption with alternative fuel and/or advanced technology use; VMT does not change.
[c]Group 3 involves options that would change the price of conventional fuel and/or vehicle operation, leading to changes in fuel consumption and VMT.
[d]Group 4 involves other options that could change petroleum use and VMT.

1.1.2 Assessing Environmental Benefits Due to Petroleum Reduction

For the purposes of this study, DENB is defined as the economic value of net reductions in air emissions and multimedia impacts for a given petroleum reduction option.[2] Here, air emission reductions refer to reductions in the criteria pollutants — specifically, hydrocarbons (HC), oxides of nitrogen (NO_x), carbon monoxide (CO), and particulate matter (PM) — and greenhouse gases (GHG). Reductions in ground and water pollution impacts refer to a reduction in the volume of spills that occur primarily during bulk fuel handling, transport, and storage.

This section describes how the DENB is calculated based on the air emissions and multimedia impact reduction achieved for a given petroleum reduction option.

Assessing Air Emissions and Multimedia Impact Reduction

Criteria pollutant and GHG emission factors were determined for each of the fuels utilized by options listed in Table 1-1, with a separate set of factors for light-duty vehicles (LDVs) and MDVs to HDVs.[3] Recognizing that the petroleum reduction options are phased in over time, emission factors were optimized such that the total anticipated emissions reduction for later years in the 2002-2030 time frame are most representative. The annual emission reductions for the early years — when fewer vehicles are participating in the petroleum reduction options — are less representative and underpredict the possible emissions benefits. We assumed that all vehicles, regardless of model year, meet the most stringent standards, even though these standards will be phased in over time. Section 2 presents a detailed description of how the emission factors were determined.

For each of the petroleum reduction options listed in Table 1-1, we determined the emissions reduction as follows. First, avoided petroleum fuel usage and vehicle mileage were obtained from the Task 3 Report for each of these options. Likewise, any alternative fuel or conventional fuel consumed also was obtained from the Task 3 Report. Then, the total emissions reduction for an option was determined by multiplying the fuel and mileage values for that option by the appropriate fuel-cycle and vehicle operation emission factors, respectively, and combined as shown in Figures 1-2 through 1-4.

Baseline vehicles — vehicles whose fuel consumption and mileage are displaced under a given petroleum reduction option — are assumed to be gasoline partial zero-emission vehicles (PZEVs) for LDV options and assumed to be advanced diesel vehicles meeting MY2007 standards with ultra-low-sulfur diesel (ULSD) for MDV and HDV options. This assumption tends to under predict emission benefits, particularly those associated with zero-emission vehicle technologies. Baseline vehicles are assumed to be those vehicles that would operate in the absence of these petroleum reduction options. See the Task 3 Report (Energy Commission 2002) for a more detailed description of baseline fleet and new fleet characteristics for each option.

[2] In the Task 4 report, the DENB and the external cost of petroleum dependency for each option are combined with its corresponding DNNB — as determined in the Task 3 report — to provide the direct net benefits for that option.

[3] Emission factors quantify the marginal air emissions per unit fuel used (for fuel cycle emissions) or per mile driven (for tailpipe and evaporative emissions).

$$\boxed{\begin{array}{c}\text{Total Fuel Cycle}\\ \text{Emissions Reduced}\\ \text{(grams)}\end{array}} = \left(\boxed{\begin{array}{c}\text{Conventional Fuel}\\ \text{Avoided}\\ \text{(gallons)}\end{array}} \times \boxed{\begin{array}{c}\text{Conventional Fuel}\\ \text{Emission Factor*}\\ \text{(g/gallon)}\end{array}}\right) - \left(\boxed{\begin{array}{c}\text{Alternative Fuel}\\ \text{Consumed}\\ \text{(units of fuel)}\end{array}} \times \boxed{\begin{array}{c}\text{Alternative Fuel}\\ \text{Emission Factor*}\\ \text{(g/unit of fuel)}\end{array}}\right) - \left(\boxed{\begin{array}{c}\text{Conventional Fuel}\\ \text{Consumed}\\ \text{(gallons)}\end{array}} \times \boxed{\begin{array}{c}\text{Conventional Fuel}\\ \text{Emission Factor*}\\ \text{(g/gallon)}\end{array}}\right)$$

*Fuel cycle emission factors are developed for each fuel, and account for all upstream (processing, delivery, etc.) emission sources

Figure 1-2. Formula for Determining Fuel-cycle Emissions Reduction

$$\boxed{\begin{array}{c}\text{Total Vehicle}\\ \text{Emissions Reduced}\\ \text{(grams)}\end{array}} = \left(\boxed{\begin{array}{c}\text{Conventional Fuel}\\ \text{Operation Avoided}\\ \text{(vehicle miles}\\ \text{travelled)}\end{array}} \times \boxed{\begin{array}{c}\text{Conventional Fuel}\\ \text{Emission Factor**}\\ \text{(g/mile)}\end{array}}\right) - \left(\boxed{\begin{array}{c}\text{Alternative Fuel}\\ \text{Operation}\\ \text{(vehicle miles}\\ \text{travelled)}\end{array}} \times \boxed{\begin{array}{c}\text{Alternative Fuel}\\ \text{Emission Factor**}\\ \text{(g/mile)}\end{array}}\right) - \left(\boxed{\begin{array}{c}\text{Conventional Fuel}\\ \text{Operation}\\ \text{(vehicle miles}\\ \text{travelled)}\end{array}} \times \boxed{\begin{array}{c}\text{Conventional Fuel}\\ \text{Emission Factor**}\\ \text{(g/mile)}\end{array}}\right)$$

**Vehicle operation emission factors are developed for each fuel and account for in-use emissions

Figure 1-3. Formula for Determining Vehicle Emissions Reduction

Total Fuel Cycle Emissions Reduced (grams)	+	Total Vehicle Emissions Reduced (grams)	=	Total Emissions Reduced * (grams)

* The Total Emissions Reduced is converted from grams to tons using the conversion: 908,000 g = 1 ton. Throughout this report, "ton" refers to a U.S. short ton.

Figure 1-4. Formula for Determining Total Emissions Reduction for a Given Petroleum Displacement Option

Some Group 2 options incur the use of a fuel other than the baseline fuel. For such options, separate emission factors were used for the baseline vehicle fuel consumption and mileage and the alternative vehicle fuel consumption and mileage, as shown in Figures 1-2 through 1-4. In some Group 2 options, such as plug-in gasoline-electric hybrids, the alternative fuel vehicle uses a combination of alternative fuel and conventional fuel. For such cases, both alternative fuel emission factors and conventional fuel emission factors are used as indicated to determine the net emissions reduction. The net air emissions reduction for options from all groups are presented in Section 2.

The DENB associated with multimedia impact reduction is based on the gallons of liquid fuel displaced for a given option. For options that involve a liquid fuel, the ground and water impact reduction is determined by calculating the net liquid fuel use avoided, in gallons. Fuels such as hydrogen or propane (LPG) that become gases in the atmosphere if accidentally released are assumed to have no spill cleanup costs, and thus no ground and water impacts.[4] For the ground and water impact calculations, total fuel displaced (gallons) takes the place of "Total Emission Reduced" in Figure 1-4.

Assessing DENB

Air emission and ground and water impact reductions are converted to DENB using valuation factors expressed in 2001$/ton or 2001$/gallon, respectively. For each of the air emission species under consideration, a valuation factor was determined using previous studies of effective damage costs due to such emissions. Likewise, the valuation of ground and water impacts was determined by examining previous studies on spill cleanup and water contamination costs. Section 3 explains in further detail how these valuation factors are determined.

The DENB for a given option was determined as follows. First, the air emissions and multimedia impact reduction presented in Section 1 is multiplied by the corresponding valuation factor for each year the option is in place (see Figure 1-5). These results are presented in Section 4 for all options analyzed.

[4] Criteria pollutant emissions generated due to spills are incorporated into the fuel cycle emission factors.

Net Emissions Reduced Species 1, Year 1 (tons)	X	Emission Valuation Factor* (2001$/ton)	=	DENB (no discount) Species 1, Year 1 (2001$)

DENB (no discount) Species 1, Year 1 (2001$)	+	DENB (no discount) Species 2, Year 1 (2001$)	+ … +	DENB (no discount) Last Species, Year 1 (2001$)	=	DENB (no discount) Year 1 (2001$)

*A similar approach is used for the ground and water impacts, where the net liquid fuel displaced in a given year is multiplied by a ground and water impact valuation factor, in 2001$/gallon.

Figure 1-5. Formula for Determining the DENB (with No Discount) for a Given Year

Then, these monetary estimates for each future year are discounted using a present value (PV) analysis and added together.[5] The now-discounted monetary estimates for all emissions and multimedia impact reductions in a given option are added together to form the option's DENB (see Figure 1-6). Again, these results are provided in Section 4.

DENB (no discount) Year 1 (2001$)	X	Present Value Factor (for CY2001)	=	DENB Year 1 (2001$)

DENB Option X, Year 1 (2001$)	+	DENB Option X, Year 2 (2001$)	+ … +	DENB Option X, Last Year (2001$)	=	DENB, Option X (2001$)

Figure 1-6. Formula for Determining the DENB for a Given Option

The DENB can be compared or added to the results of the DNNB analyses provided in Task 3. Together the DENB and DNNB represent the direct net benefits (DNB) for a given petroleum reduction option.

A 5-percent discount rate was used for this analysis. This rate is representative of the societal decision-making in California, and has been used in other state policy-oriented analyses. This rate is low compared to an 8-percent average rate for industry, and could be considered too high for such long-term environmental benefits as reducing global warming.

[5] The PV analysis discounts future year costs and benefits at 5 percent annually. This represents the loss in opportunity for achieving present-day air emissions and ground and water impact reductions and, hence, the loss in value of the associated benefits. Under this approach, emissions reductions in the near-term are more valuable than equivalent emission reductions achieved in later years.

1.2 External Cost of Petroleum Dependency

The impact on the external cost of petroleum dependency (ECPD) for a given petroleum reduction option is based on the petroleum displacement achieved by that option. The ECPD for a given option is calculated using the same methodology as previously described for the DENB analysis, except that the net petroleum fuel displaced and the 2001 \$/gallon[6] valuation factor are used in place of the Net Emissions Reduced and Emission Valuation Factor, respectively (see Figure 1-5). The remainder of the calculation is performed in the same manner as for calculating the DENB for that option. Further discussion of ECPD can be found in Section 3.

1.3 Economic Benefits of Petroleum Reduction Analysis Methodology

In addition to the DENB and ECPD analyses described above, the potential economic impacts of reducing petroleum consumption were estimated using a sophisticated economic model of the California economy. The model was used to estimate economic conditions without any petroleum reduction options (base year analyses) and then used to analyze the effect of petroleum reduction and/or displacement scenarios (combinations of petroleum reduction options). The results are expressed as detailed effects on the California economy, and as such can be used to "screen" how various scenarios may affect the California economy. A summary of these results is presented in Section 4. The detailed methodology, analysis, and results of this analysis are presented in Appendix A.

[6] The ECPD valuation is based on gallons of gasoline and applied for gasoline or diesel gallons displaced. We did not make any distinction between gasoline or diesel fuels. ECPD is only considered for petroleum based fuels.

2. Air Emission Reduction

The analysis presented in this section quantifies the air emission reduction for each of the petroleum reduction options in Table 1-1. This analysis will account for the net reduction in vehicle tailpipe and evaporative emissions, as well as emissions associated with fuel production, transport, and storage. The emission reductions quantified in this section, along with the multimedia impacts, are used to determine the DENB for each option, the results of which are presented in Section 4.

2.1 Emission Sources Associated with Vehicle Operation

In order to perform an emissions impact analysis, the various emission sources must be identified. Figure 2-1 identifies the activities that comprise the life cycle of vehicle fuel use, from manufacturing a fuel at a fuel production facility and producing refined product to using the fuel and recycling vehicles. The analysis performed in this study estimates air emission impacts for vehicle operation and the related fuel cycle only — those activities enclosed by the dashed box in Figure 2-1 — as these activities have a more direct connection with petroleum reduction and miles driven.

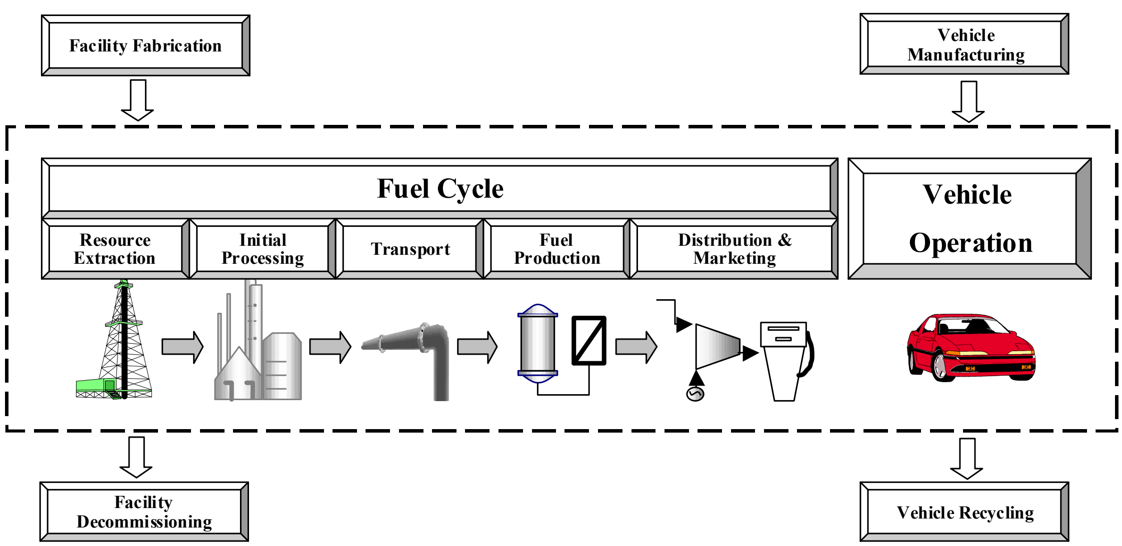


Figure 2-1. Activities Related to Fuel Production and Vehicle Operation

Fuel cycle (well-to-tank) emissions include emissions generated during the extraction of feedstocks, processing or refining, transport, and local distribution. The construction and decommissioning of facilities are not included in this analysis. Within the context of this study, it was assumed that a change in fuel consumption would not result in a significant change in California fuel production facility capacity.

Vehicle cycle (tank-to-wheels) emissions include vehicle evaporative emissions and vehicle tailpipe emissions. Emissions associated with producing and recycling the vehicle are not included in the analysis for several reasons. According to Rainer Friedrich and Peter Bickel (Friedrich and Bickel 2001), vehicle production is on the order of 20 percent of overall emissions and this contribution increases as vehicles meet more stringent emissions standards. However, whether or not options that reduce petroleum usage would also reduce vehicle productions emissions is unclear and requires further analysis outside the scope of this report. With some strategies such as VMT reductions, an estimate of vehicle manufacturing and recycling emissions impact on a per-mile basis would provide a poor estimate of the actual impacts. These impacts may well remain constant over the calendar life of the vehicle even as mileage is reduced. Similarly, because we are performing a marginal analysis comparing baseline conventional technologies to advanced technologies, it is not clear whether there would be any changes in production energy use or emissions between the two.

Once the relevant segments of the vehicle fuel life cycle were identified as indicated above, several assumptions were developed to reduce the complexity of the fuel cycle portion of the analysis. These assumptions are identified in Table 2-1 for fuels associated with a petroleum reduction option.

Table 2-1. Assumptions for Fuel-Cycle Emission Analysis in the SoCAB

Fuel	Analysis Assumptions
Gasoline	Import finished product. Zero emissions for crude oil production and refinery. Considered refinery capacity expansion in Appendix C, but with no emissions impact.
Diesel, LPG	Import finished product. Zero emissions for crude oil production and refinery. Considered refinery capacity expansion in Appendix C, but with no emissions impact.
Methanol, LPG, FTD from natural gas, ethanol from biomass	Produced outside of the South Coast or California. Feedstock extraction and refinery do not result in SoCAB or California emissions.
Electricity (for EVs, plug-in hybrids)	Incremental power from natural gas. NO_x would be zero for electric power generation due to purchase of offsets and emission requirements.

Future increases in fuel production and demand that would occur in the absence of petroleum reduction options are assumed to be met by the newest and most efficient facilities. Thus, any increases in fuel production or power generation due to a petroleum reduction option were assumed to come from the newest, and thus most efficient, plants in use. As a consequence of this assumption, no hydroelectric or nuclear power was included in the fuel cycle analysis, as reducing gasoline demand by increasing electric power output for EVs would not increase the output from hydroelectric or nuclear power-generation facilities. It was assumed that any incremental demand for electric power created under a petroleum reduction option would be met by natural gas. Another assumption made in this analysis was that the natural gas used to fuel CNG and hydrogen vehicles will be transported over substantial distances. Some analysts argue that natural gas resources in the U.S. are limited and if hydrogen FCVs or CNG vehicles are used on a large-scale basis, additional natural gas would need to come from foreign sources of LNG. In this analysis, foreign sources of LNG were not included, but pipeline transportation of natural gas from Canada was included. This pipeline transportation requires a substantial amount of energy and results in higher GHG emissions for natural gas or natural-gas-derived fuels.

2.2 Emission Factor Development

The assumptions above provide the basis for establishing fuel-specific emission factors — factors that indicate the relevant criteria pollutant and GHG emissions given the amount of a particular fuel used and miles driven in a petroleum reduction option. Three categories of emission factors were determined for each fuel under consideration:

- Local (in-state) fuel-cycle criteria pollutant emissions — one factor each for NO_x, CO, NMOG; as well as various Toxics (Benzene, 1,3 Butadiene, Formaldehyde, Acetaldehyde), and PM sources (Combustion Exhaust PM and Power Plant PM)[7]
- Local in-use vehicle criteria pollutant emissions — one factor for each of the criteria pollutants, as described above
- Worldwide fuel-cycle and vehicle GHG emissions — one factor representing GHG emissions (CO_2, N_2O, and CH_4) from the fuel cycle and vehicle operation – on a CO_2-equivalent basis

The fuel cycle emissions factors were determined on a per unit fuel basis. This approach allows the most direct determination of criteria pollutant emission factors as many local fuel cycle emissions are regulated on a per gallon basis. Because state and federal LDV emission standards are set on a per-mile basis, the in-use vehicle emission factors were determined on a per-mile basis as well.[8] The vehicle emission factors incorporate the tailpipe and evaporative emissions related to vehicle operation and on-board fuel storage. Emission factors were developed by assuming that fuel-cycle and vehicle emission sources comply with all applicable state and federal requirements.

A previous ARB study (CARB 2001a) estimated the fuel cycle emission impacts associated with diesel, methanol, LPG, and FTD production in 2010, but did not provide estimates for future years. In order to determine the fuel cycle emission impacts for future years, we assumed a complete roll-in of the MY2007 heavy-duty emission standards for heavy-duty engines. Liquid fuel storage facilities were assumed to be at best available control technology (BACT) levels by 2020 (likely for new facilities). Finally, power plant efficiency was assumed to improve in future years; thus, power plant related carbon dioxide (CO_2) emissions were reduced in 2020 and beyond. These assumptions tend to under predict the emission benefits associated with the heavy-duty options evaluated.

[7] Although other types of toxics and PM could be considered — such as Polycyclic Aromatic Hydrocarbons (PAHs) or tire- and brake-generated PM — emission factors for these were not determined under this analysis.

[8] Heavy-duty vehicle emission standards are usually given in g/bhp-hr. Heavy-duty vehicle emission factors determined for this analysis were converted to g/mi using typical HDV operating parameters.

2.2.1 Definition of Fuel Cycles

As indicated in Section 1, fuel cycle emission factors were first determined for the SoCAB. The San Francisco Bay Area also has marine terminals; given this and other similarities to the SoCAB, the emission factors developed for the SoCAB are assumed a reasonable surrogate for the Bay Area and other urban areas in California.

The fuel cycle emission factors determined in this study represent the weighted average of different production and distribution technologies described in this section. Some fuel/feedstock combinations, such as methanol produced from natural gas, were represented separately, while others were combined to simplify the comparison of fuels. The particular scenarios, feedstock mixes, and production and distribution technologies are described in the following sections.

Feedstock Combinations

Table 2-2 summarizes the fuel/feedstock combinations considered in this study. As indicated in the table, several fuels are made from the same feedstock and some fuels can be produced from multiple feedstocks.

Table 2-2. Vehicle Fuels Considered in this Study

Feedstock	Fuel[a]	Type of Fuel[b]
Petroleum	Gasoline	Liquid, crude and refined marine import
	Diesel	Liquid, crude and refined marine import
	LPG	Liquid, marine crude import
Natural Gas	LPG	Liquid, rail transport
	FTD	Liquid, marine import
	CNG	Gaseous
	LNG	Liquid, marine import
	Methanol	Liquid, marine import
	Hydrogen	Gaseous, compressed
	Electricity	Electric Power
Electricity	Hydrogen	Gaseous, compressed
Corn	Ethanol	Liquid, rail and marine transport
Biomass	Ethanol	Liquid, rail or pipeline transport

[a] LPG: Liquefied petroleum gas, FTD: Fischer-Tropsch diesel (synthetic diesel), CNG: compressed natural gas, LNG: liquefied natural gas.
[b] Appendix C indicates how emission factors for a given fuel were developed.

Different mixes of feedstocks can be used in fuel production. For example, a variety of crude oil sources make up the feedstock for California refineries, and this mixture will change in the future. While most methanol in the world is produced from natural gas, biomass resources —

such as landfill gas, urban waste, sewage sludge, and woody materials — also can be used as methanol feedstocks. Producing methanol from these biomass feedstocks would result in almost no fossil fuel CO_2 emissions, and the local emissions in urban areas would be similar to those for other liquid fuel options as discussed in an ARB study of fuel cycle emissions from alternative fuels (CARB 2001a).

Natural gas is produced from gas fields and as a byproduct of oil production. Natural gas can be used for many purposes, including the manufacture of synthetic liquid fuels and methanol. LPG is produced during oil refining and derived from natural gas liquids, as a product of oil and natural gas production. Electricity can be produced from a myriad of feedstocks, which range in GHG emission impact from very small, if produced from solar energy, to very large, if produced from coal.

Fuel cycle emissions are largely associated with the fuel properties and the fuel transportation mode. The feedstock type is typically related to a particular geographic region, transportation mode, and transportation distance. For example, local criteria pollutant emissions due to rail-based LPG transport were determined by counting the length of in-state rail traversed in the transportation of LPG from western states.

Geographic Distribution

Because some fuels associated with petroleum reduction options are produced outside of California, some emissions along the fuel cycle will not directly impact California urban areas. For this reason, it is important to identify the percentage of feedstock extracted or fuel produced in a given geographical area. In order to help evaluate the impact on local emission inventories and air quality, and take into consideration the differences between local emission rules, fuel cycle emissions were geographically categorized. Fuel cycle emissions from fuel production were allocated according to the locations in Table 2-3. For example, emissions for ships entering and exiting the San Pedro ports are attributed to the SoCAB for a portion of the trip. The balance of these emissions is attributed to the rest of the world. Both land and sea transport emissions are allocated proportionally according to their transport route. This geographic distinction was not made for GHG emissions impact as the effect of GHGs are considered global in nature.

This study is intended to be used to evaluate incremental emissions from fuel production associated with a petroleum reduction option. The interpretation of which emissions correspond to fuel production depends on several factors that are discussed in Section 2.2.2. See Appendix C for additional discussion.

Table 2-3. Locations of Emissions

Location	Acronym
Within the SoCAB	SC
Within California, but outside the SoCAB	CA
Within the U.S., but outside of California	U.S.
Rest of the World, outside the U.S.	ROW

Petroleum Fuels: Gasoline, Diesel, and LPG

Gasoline, diesel, and LPG are produced from crude oil. These fuels share the same crude oil feedstock and therefore the same extraction and feedstock distribution paths (LPG is also produced from natural gas).

Imported refined gasoline and diesel or refined gasoline and diesel components enter the SoCAB by marine transport. As a result of these imported fuels being complete[9] when they arrive in the SoCAB, there are no emissions associated with crude oil production or refining in the region. There are, however, local marine vessel emissions associated with their importation.

LPG is also imported to California in significant quantities but it is transported by rail. Its uses under the petroleum reduction options are as a motor fuel or as a refinery fuel or feedstock. This LPG comes from natural gas processing facilities in Canada and the southwest United States, and from refineries in Utah.

After each of the imported fuels is transported to the South Coast, it is stored in bulk tanks and distributed to fueling stations in tank trucks. Emissions resulting from the storage of petroleum and petroleum fuels consist of fugitive and spillage emissions.

Vapor losses occur primarily when tank trucks are filled at the bulk terminal, unloaded at the fueling station, and during vehicle fueling. Spillage during vehicle fueling is also a significant source of emissions

Natural-Gas-Based Fuels: CNG, Hydrogen, LPG, FTD, Methanol, and LNG

The natural gas and natural-gas-based fuels for transportation included in this study are CNG, hydrogen, LPG, FTD, methanol, and LNG. Natural gas is recovered and collected from oil and natural gas fields. The gas is then transported by pipeline to processing facilities, which are usually located near the gas field. For commercial natural gas, the gas is processed to remove propane, butane, moisture, sulfur compounds, and CO_2. When flared gas is used as a feedstock, no CO_2 emissions from the natural gas feedstock are attributable to the end product.

All of the natural-gas-based fuels have identical fuel cycles in the extraction and feedstock transport phases. After this point, the processing steps differ, as follows.

CNG and Hydrogen

Natural gas is a feedstock for CNG and for hydrogen produced by steam reforming. The onsite steam reformer option for generating hydrogen was selected for this analysis, as it appears to provide the best opportunity for low cost and widespread distribution (ADL 2002, Thomas 2000, and Simbeck 2002).

[9] Any additional refining to manufacture gasoline or diesel fuels meeting California specifications is not included in this analysis.

The fuel cycle emissions from CNG and compressed hydrogen are similar due to their similar distribution phases. In this study, we assumed that hydrogen is produced from natural gas by a refueling station onsite reformer. As a result, the fuel cycle emissions for both fuels are identical, except that hydrogen production produces reformer emissions and avoids small methane or NMOG refueling emissions.

LPG

LPG can be produced from the extracted liquids of natural gas as a byproduct of petroleum refining. There are no LPG production emissions in the SoCAB associated with the petroleum reduction options since LPG processing, like the case of petroleum refining, occurs in Canada or the Southwestern states. The principal difference affecting LPG fuel cycle emissions is the additional transportation by rail car of LPG from outside California. The fuel cycle steps for LPG parallel those for diesel and gasoline after it reaches the SoCAB except for pressurization of tanks. Fugitive emissions from LPG transfer occur when fuel is transferred from storage tanks, rail cars, trucks, and vehicle tanks. When a tank is filled, liquid LPG fills the tank, LPG vapors condense, and a small amount of LPG vapor is vented as part of the tank filling procedure.

Synthetic Diesel (FTD)

Synthetic diesel and other synthetic liquid fuels are formed from a three-step process known as the Fischer-Tropsch (FT) Process, which converts coal, biomass, or natural gas to liquid fuels. It is an attractive alternative air quality option to conventional diesel fuels because it contains no sulfur or aromatics and has a higher cetane number. This study considers only synthetic diesel from natural gas because it is the most economically attractive option.

As a result of this process, the fuel cycle for synthetic diesel at the upstream end is similar to that of methanol.

Methanol

Methanol, like synthetic diesel, can be produced from a variety of feedstocks. Most methanol in the world and all the methanol used in California as a vehicle fuel is made from natural gas. The conversion process typically used — steam reforming — is similar to the process used to make synthetic diesel, but uses different catalysts, temperatures, and pressures. The upstream fuel cycle is similar to that for CNG. Fuel distribution for methanol consists of bulk storage terminals and transfer systems similar to those for gasoline. Methanol used as part of a petroleum reduction option is imported to California by marine transport.

LNG

LNG is produced from natural gas in liquefaction facilities. As a result, the extraction phases for LNG are the same as those for other natural gas fuels. The natural gas is compressed, cooled, and expanded in a multi-stage operation, using natural-gas-powered engines for compression. LNG is then stored as a cryogenic liquid in insulated storage vessels. LNG can be produced in a variety of locations. However, most of the resources for LNG lie outside of California. The analysis in this study is based on LNG imported from out-of-state sources that are shipped to California by rail. The primary source of LNG is assumed to be the western United States.

The distribution of LNG has several emission sources, including venting from storage tanks, tanker truck fuel transfers, and tanker truck gas purging.

Biomass Fuels

Ethanol can be produced from various sources, including many types of biomass. There is potential for significant production of ethanol within California from cellulosic- and starch-based biomass, such as agricultural residues and sugar beets. Non-starch residues are first hydrolyzed and converted to starches. The starch-based biomass is then fermented and converted to ethanol. However, in this analysis, ethanol is produced from the fermentation of corn and imported from corn-producing states in the midwestern United States by rail. Once the fuel is transported to the SoCAB, its emission sources are much like those of other liquid transportation fuels.

Electric Power Generation

Due to the ARB ZEV rules, sales of EVs are expected to increase over the timeframe considered in this study. In California, the additional electricity required to power EVs and other electro-drive equipment will be generated using natural gas. The rationale behind this assumption is discussed in a prior study on fuel cycle emissions (CARB 2001a). Because all electricity used under a given petroleum reduction option is expected to be derived from natural gas, the fuel extraction and transport aspects of the fuel cycle are identical to those of other natural-gas-based fuels. The distribution of electricity is not associated with any emissions. However, the losses in the fuel chain affect how much power must be produced at the power plant.

2.2.2 Determining Local Emission Reductions

Using the results from the fuel cycle and vehicle emissions analyses discussed above, emissions factors were determined for each of the fuels used in the petroleum reduction options. Table 2-4 shows the criteria pollutant emission factors for the fuel cycle and for vehicle operation. The table also shows the combined fuel cycle and vehicle GHG emission factors on a CO_2 equivalent g/unit fuel basis. GHG emissions were determined from the energy inputs associated with fuel production, transportation and distribution, and vehicle operation.

Local Fuel Cycle Emissions

Fuel cycle criteria pollutant emission factors represent primarily fuel transport, storage, and distribution emissions for all fuels except electricity. For criteria pollutants, the net result of the SoCAB petroleum reduction option fuel cycle analysis indicated that fuel cycle NO_x emissions associated with petroleum reduction options can be attributed to tanker ship and truck emissions in the SoCAB. All other potential sources of fuel cycle NO_x emissions are either controlled locally or associated with fuel production outside of the SoCAB. Fuel cycle non-methane

Table 2-4. In-state Criteria Pollutants and GHG Emission Factors for Urban Areas in California

	LDV											HDV[a]				
Pollutant	RFG3	RFD	LPG NG	M100 NG FCV	CNG	LNG	cH2 SR NG	Electricity (SoCAB)	E10	E65	E85	RFD	CNG	LNG	B20	FTD33 Blend
Fuel Cycle (g/unit fuel)	gallon	gallon	gallon	gallon	100 scf	gallon	kg	kWh	gallon	gallon	gallon	gallon	100 scf	gallon	gallon	gallon
NO_x	0.037	0.038	0.108	0.035	0.002	0.031	0.061	0.0001	0.041	0.082	0.097	0.038	0.002	0.031	0.069	0.037
CO	0.029	0.032	0.039	0.029	0.079	0.022	0.243	0.055	0.030	0.039	0.042	0.032	0.079	0.022	0.038	0.031
NMOG	0.569	0.337	0.831	0.122	0.008	0.188	0.038	0.0034	0.570	0.564	0.555	0.337	0.008	0.188	0.339	0.326
Toxics (mg/unit fuel)																
Benzene	4.82	0.125	0.324	0.117	0.003	0.098	0.123	0.015	4.540	2.61	1.48	0.125	0.003	0.090	0.206	0.122
1,3 Butadiene	0.011	0.012	0.030	0.011	0.000	0.009	0.001	0.000	0.012	0.026	0.029	0.012	0.000	0.008	0.019	0.011
Formalehyde	0.878	0.904	2.33	0.842	0.024	0.707	0.331	0.046	0.946	2.02	2.31	0.904	0.024	0.601	1.49	0.879
Acetaldehyde	0.437	0.450	1.160	0.419	0.036	0.351	0.069	0.001	0.470	1.00	1.15	0.450	0.036	0.363	0.740	0.437
Particulate Matter (g/unit fuel)																
Exhaust PM	0.002	0.002	0.002	0.002	0.000	0.002	—	—	0.002	0.003	0.003	0.002	—	0.002	0.003	0.002
Power Plant PM	—[b]	—	—	—	0.009	—	0.046	0.007	—	—	—	—	0.009	—	—	—
Vehicle (g/mi)																
NO_x	0.024	0.024	0.024	0.000	0.024	0.024	—	—	0.024	0.024	0.024	0.890	0.890	0.890	0.890	0.890
CO	0.400	0.400	0.400	0.000	0.400	0.400	—	—	0.400	0.400	0.400	2.07	2.07	2.07	2.07	2.07
NMOG	0.029	0.010	0.005	0.005	0.005	0.005	—	—	0.029	0.029	0.029	0.221	0.220	0.220	0.221	0.221
Toxics (mg/mi)																
Benzene	0.350	0.235	0.015	0.000	0.015	0.015	—	—	0.350	0.052	0.052	5.18	0.656	0.656	5.18	3.45
1,3 Butadiene	0.036	0.022	0.006	0.000	0.006	0.006	—	—	0.036	0.036	0.036	0.492	0.262	0.262	0.492	0.492
Formaldehyde	0.080	1.730	0.649	0.080	0.649	0.649	—	—	0.080	0.080	0.080	38.1	28.5	28.5	38.1	38.1
Acetaldehyde	0.020	0.865	0.015	0.000	0.015	0.015	—	—	0.020	0.020	0.020	19.0	0.656	0.656	19.0	19.0
Particulate Matter (g/mi)																
Exhaust PM	0.002	0.010	0.002	0.000	0.002	0.002	—	—	0.002	0.002	0.002	0.035	0.035	0.035	0.035	0.035
Greenhouse Gases (g/unit fuel)	11,200	12,600	6,900	5,800	7,880	6,570	13,400	470	10,800	7,240	6,300	12,600	7,880	6,570	11,000	12,900

[a] Abbreviations used: reformulated gasoline Phase III (RFG3), reformulated diesel (RFD) meeting ARB and EPA ultra low sulfur diesel requirement (<15 ppm), Fischer Tropsch Diesel (FTD), 100% methanol from natural gas (M100 NG), 85% ethanol mixed with 15% gasoline (E85), compressed hydrogen from steam reforming natural gas (cH_2 NG SR), 20% Biodiesel blended with 80% RFD (B20).

[b] — refers to zero emissions.

organic gas (NMOG)[10] emissions correspond to fuel storage and distribution activities as well as power production for EVs. More detailed results from the analysis are presented later in this section and in Appendix C.

For reformulated diesel (RFD), CNG, and LNG, fuel cycle emissions factors are shown in Table 2-4 for both LDVs and HDVs, as there could be minor differences in refueling emissions. The main difference involves the spillage rate for vehicle refueling. In the case of HDVs, fuel flowrates and tank volumes are generally larger, and the quantity of fuel spilled may also increase due to larger fuel connection fittings. Some HDVs are fueled with “dry break” fittings that shut off automatically when the fuel nozzle is removed from the vehicle. Even these fittings can result in small levels of spillage.

In the case of onsite hydrogen production, CNG compression, and electric power production, the fuels are all produced from natural gas. Some storage losses are associated with natural gas transmission. The emissions from natural gas pipeline engines also contribute to fuel cycle emissions.

Local Vehicle Emissions

Emission factors for LDVs and HDVs were shown separately in Table 2-4. NOx, CO, and NMOG emissions from LDVs are estimated from ARB’s assessment of the in-use emissions from partial zero-emission vehicles (PZEVs) using EMFAC 2002, version 2.2 (EMFAC). In-use emissions from PZEVs are expected to be different than the standard due to deterioration over time, emission control malfunctions, and lower zero-mileage emissions that allow for compliance over the life of the vehicle. PZEVs are subject to a 150,000-mile emissions durability and warrantee requirement rather than the typical 100,000-mile emissions durability and warrantee requirement. This tends to ensure that emissions from PZEVs remain at or below the standard. The assumption that all LDVs meet PZEV standards under predicts the emission benefits of petroleum reduction options since it is not expected even in the 2020 timeframe that all light-duty vehicles will be PZEVs. This is especially true for zero-emission technologies such as battery-electric and fuel cell vehicles where this assumption decreases their relative environmental benefits.

EMFAC emission factor estimates for PZEVs are shown in Table 2-5. These estimates were made for model year (MY) 2010 PZEVs and results are shown for calendar years (CY) 2010 and 2020. Average factors were determined from the CY2010 and CY2020 results.

Table 2-5. EMFAC Estimates of PZEV NO_x, CO, and NMOG Emission Factors (g/mi)

	Average Emissions CY2010-CY2020		*CY2010 Emissions*		*CY2020 Emissions*	
MY2010	***All Exhaust***	***Total Emissions***	***All Exhaust***	***Total Emissions***	***All Exhaust***	***Total Emissions***
ROG	0.0046	0.0288	0.0032	0.0158	0.0061	0.0418
CO	0.3522	0.3522	0.2361	0.2361	0.4684	0.4684
NOx	0.0237	0.0237	0.0169	0.0169	0.0305	0.0305

Source: EMFAC2002, Version 2.2, South Coast

[10] Hydrocarbon emissions are classified as reactive organic gases (ROG) or non-methane organic gases (NMOG).

For the purposes of this report, ARB staff quantified PM emissions from PZEVs external to the EMFAC model. EMFAC does not differentiate PM emissions from PZEVs relative to other technology types (LEV, ULEV, etc.), nor does EMFAC reflect the possibility of diesel PZEVs. ARB staff considered PM data for both gasoline and diesel vehicles from the *Measurement of Primary Particulate Matter Emissions from Light-Duty Motor Vehicles*, December 1998, done by the Coordinating Research Council, Inc. and the South Coast Air Quality Management District (CRC). For diesel vehicles ARB staff also considered information contained in the SAE paper by Joseph McDonald and Byron Bunker (SAE).

To quantify PM emissions from gasoline PZEVs, ARB staff evaluated vehicles in the CRC report whose criteria pollutant emission levels were as close to the PZEV standard as existed in the report. Unfortunately, none of the gasoline vehicles in the CRC report met all of the PZEV criteria pollutant standards and the closest still had criteria pollutant emission levels significantly higher than PZEV standards. There were nine vehicles in the CRC report that had criteria pollutant levels at or below 0.15 g/mi HC, 1.5 g/mi CO, and 0.2 g/mi NO_x as summarized in Table 2-6. These nine vehicles had an average PM emission rate of 0.0009 g/mi and most of these vehicles had less than 40,000 miles on them. This is approximately three times lower than the average PM emission rate for all 1991-1997 model year vehicles in the CRC report (0.0025 g/mi), indicating that there may be a correlation between low criteria pollutant emissions and low PM emissions. As a conservative estimate, ARB staff assumed that PM emissions from gasoline PZEVs would be approximately 0.002 g/mi over the life of the PZEV.

Table 2-6. CRC Data Meeting Emissions Lower than 0.15 g/mi HC, 1.5 g/mi CO, and 0.2 g/mi NO_x

Model Year	Make	Model	Miles	HC g/mi	CO g/mi	NOx g/mi	PM mg/mi	PM g/mi
1996	Dodge	Dakota	3,722	0.11	0.89	0.12	1.92	0.0019
1996	Ford	Escort	13,719	0.06	0.87	0.08	0.46	0.0005
1996	Acura	Integra	4,280	0.11	0.65	0.19	0.18	0.0002
1996	Ford	Explorer	15,164	0.11	0.80	0.16	2.49	0.0025
1996	Nissan	Sentra	13,845	0.15	0.89	0.19	0.48	0.0005
1996	Ford	F-150	24,595	0.11	1.00	0.13	0.89	0.0009
1995	Honda	Accord LX	37,161	0.08	1.09	0.19	0.34	0.0003
1994	Ford	Escort LX	31,924	0.12	0.72	0.20	1.04	0.0010
1993	Ford	Ranger XCAB	74,635	0.14	1.13	0.19	0.48	0.0005
		Averages		0.11	0.89	0.16	0.92	0.0009

Source: CRC 1998

In evaluating PM emissions from light-duty diesel PZEVs, ARB staff considered information contained in the CRC report as well as information contained in the SAE paper. The CRC report contains test data for only one light-duty diesel vehicle with a particulate trap and that vehicle achieved a PM emission rate of 0.0155 g/mi. Data in the SAE paper indicated that a Toyota Avensis prototype diesel vehicle equipped with a particulate trap could achieve PM emission levels at or below the 0.01 g/mi PZEV standard. The U.S. EPA test data contained in this paper also indicated that the Toyota vehicle could not meet NO_x and NMHC PZEV standards. Data indicating that light-duty diesel vehicles could meet or emit below the 0.01 g/mi standard are very limited and no data exists indicating that the standard could be maintained and/or that the NO_x, NMHC, and CO PZEV emission levels could be met concurrently. Therefore, rather than relying on the limited amount of information available on trap-equipped light-duty diesel vehicles, for the purposes of this report, ARB staff assumed that light-duty diesel vehicles would meet the 0.01 g/mi PM standard, otherwise, they would not be sold in California.

It is important to emphasize that data exists indicating that light-duty diesel vehicles equipped with a trap could emit at rates below the 0.01 g/mi standard. However, there is no history indicating that the automobile industry will reduce PM emissions below the standard if there is a cost in doing so. If the emission standard were such that diesel light-duty vehicles emitted at the same levels as gasoline light-duty vehicles, then it would be reasonable to assume that there would be no increase in PM emissions from a diesel vehicle relative to a gasoline vehicle. ARB staff will be closely tracking the progress made in reducing PM emissions from light-duty diesel vehicles.

For heavy-duty vehicles, it was assumed that all vehicles in the fleet would meet US EPA and ARB heavy-duty engine standards for 2010 and beyond. These standards require diesel engines to achieve emissions levels in g/bhp-hr of 0.20 for NO_x, 15.5 for CO, 0.14 for NMHC, and 0.01 for PM. In-use emissions were determined from EMFAC2000 assuming a 90 percent reduction in NO_x and PM emissions. Diesel engines have historically certified much lower than the standard for CO and NMHC emissions. EMFAC emissions factors for NMHC and CO are 0.05 g/mi and 1.01 g/mi at zero miles. These factors where increased using EMFAC deterioration rates and assuming 460,000 miles. For comparison, a factor of 4 can be use to convert from g/bhp-hr to g/mi.

Based on the above analysis, our estimates for in-use emission factors for light- and heavy-duty vehicles are summarized in Table 2-7. These estimates assume that all future vehicles will

Table 2-7. In-Use Emissions from LDVs and HDVs (g/mi)

Pollutant	LDV PZEV Gasoline	LDV PZEV Diesel [c]	2010 HDV
NO_x	0.024 [a]	0.02	0.89 [d]
CO	0.4 [a]	0.4	2.1 [e]
NMOG	0.024 [a]	0.01	0.22 [e]
Exhaust PM	0.002 [b]	0.01	0.04 [d]

[a] EMFAC2002 version 2.2, PZEV emissions over life of vehicle.
[b] ARB estimate based on data contained in the *Measurement of Primary Particulate Matter Emissions from Light-Duty Motor Vehicles*, December 1998, done by the Coordinating Research Council, Inc. and the South Coast Air Quality Management District.
[c] ARB assumption that diesel vehicles of the future will meet the SULEV/PZEV standards or will not be sold in California. For CO ARB assumed that diesel PZEVs would be similar to gasoline PZEVs.
[d] 90% reduction from EMFAC2000 MY2004.
[e] EMFAC2000, emissions after 460,000 miles with deterioration rates of 0.004 g/mi/10k for NMHC and 0.023 g/mi/10k for CO.

achieve these or lower emission levels. For most alternative fuel options, the emission levels are assumed to be the same even though alternative fuels may provide advantages in complying with emission standards. The standards are at such low levels that CNG engines or vehicles were assumed to emit NMOG and PM at the standard. Although PZEVs are intended to have zero evaporative emissions, the ARB emissions inventory includes a non-zero value of 0.02 g/mi assuming some deterioration and running loss emissions, which are not part of the zero evaporative emissions requirement.

Table 2-8 shows assumptions that were made for electric-drive and FCV technologies. For battery EVs and hydrogen FCVs, exhaust emissions are zero. Reformers from methanol fuel cell vehicles are expected to produce no NO_x, CO, or particulate, but they would produce NMOG (Coffey 2001).

Table 2-8. Low Emission Vehicle Assumptions

Pollutant	Vehicle Technology[a]
Zero NO_x	EV, cH_2 FCV, Methanol FCV
Zero CO	EV, cH_2 FCV, Methanol FCV
Zero NMOG	EV, cH_2 FCV
Zero combustion PM	EV, cH_2 FCV, Methanol FCV

[a] CNG and LNG are possible low PM options but no data are available for PZEV or MY2007 HDV certified vehicles.

2.3 Criteria Pollutant and GHG Emission Reductions

The total emissions reduction was determined for the various petroleum reduction options using the emissions factors presented in Table 2-4 and the fuel usage and vehicle mileage for each option provided in the Task 3 Report. The results of the analysis for 2002-2030 are presented in Tables 2-9 through 2-13. Additional results from the emissions reduction analysis are presented in Appendix D.

The LDV Improved Fuel Efficiency (Group 1A) options in Table 2-9 all assume that VMT would not change relative to baseline vehicle operation. Thus, these emission reductions are based solely upon fuel cycle emission reductions, which in turn are based upon the magnitude of gasoline gallons avoided. As a result, the “Full Hybrid” options — which produce the largest petroleum displacement of all the Group 1A options — provide the largest emission reduction, followed by the “Mild Hybrid” options.

The Other Fuel Efficiency (Group 1B through 1E) options presented in Table 2-10 also assume that VMT would not change relative to baseline vehicle operation. The Fuel Efficient Tires option seeks to improve fuel economy by promoting proper tire inflation and the use of more fuel-efficient tires. This option provides the largest emission reduction of all the options presented in Table 2-10 due to

Table 2-9. Estimated Emissions Reductions in 2002-2030 for Improved Fuel Economy Options (tons)

Emissions Reduction[a]	ACEEE Advanced	ACEEE Full Hybrid	ACEEE Mild Hybrid	ACEEE Moderate	ARB Full Hybrid	ARB Mild Hybrid	EEA	NRC Path 1	NRC Path 2	NRC Path 3
NO_x	4,115 ± 155	5,557 ± 133	4,969 ± 142	3,210 ± 166	5,557 ± 133	4,969 ± 142	2,351 ± 194	1,197 ± 197	2,714 ± 171	3,533 ± 161
CO	3,240 ± 122	4,375 ± 105	3,913 ± 112	2,528 ± 131	4,375 ± 105	3,913 ± 112	1,851 ± 153	942 ± 155	2,137 ± 135	2,782 ± 127
NMOG	63,260 ± 2,380	85,430 ± 2,050	76,390 ± 2,180	49,350 ± 2,550	85,430 ± 2,050	76,390 ± 2,180	36,140 ± 29,900	18,400 ± 3,040	41,730 ± 2,630	54,320 ± 2,480
Toxics	683 ± 26	922 ± 22	824 ± 24	533 ± 28	922 ± 22	824 ± 24	390 ± 32	199 ± 33	450 ± 28	586 ± 27
Particulate Matter	242 ± 9	327 ± 8	292 ± 8	189 ± 10	327 ± 8	292 ± 8	138 ± 11	70 ± 12	160 ± 10	208 ± 9
Greenhouse Gases (million tons)	1,229 ± 46	1,659 ± 40	1,484 ± 42	959 ± 50	1,659 ± 40	1,484 ± 42	702 ± 58	357 ± 59	810 ± 51	1,055 ± 48
Fraction of 2002-2030 Emissions Reduction Achieved During Indicated Time Period										
2002-2010	1%	1%	1%	1%	1%	1%	0%	1%	1%	1%
2011-2020	31%	31%	31%	31%	31%	31%	27%	31%	31%	31%
2021-2030	68%	68%	68%	68%	68%	68%	73%	68%	68%	68%

[a]Reductions were estimated for a range of gasoline prices. The reduction shown is based on a gasoline price of $1.64/gallon ±$0.17/gallon.

Table 2-10. Estimated Emissions Reductions in 2002-2030 for Other Fuel Efficiency Options (tons)

Emissions Reduction	Fuel Efficient Tires	Government Fleets	Vehicle Maintenance Displacements	High Efficiency HDVs		High Efficiency MDVs	
				High Case	Low Case	High Case	Low Case
NO_x	352	12.1	46.7	241	113	38.3	22
CO	277	9.5	36.8	203	95.3	32.2	18
NMOG	5,412	186	719	2,160	1,017	344	193
Toxics	58.4	2.0	7.8	9.6	4.5	1.5	1
Particulate Matter	20.7	0.7	2.7	15.7	7.4	2.5	1
Greenhouse Gases (million tons)	105	3.6	14.0	80.6	37.9	12.8	7.2
Fraction of 2002-2030 Emissions Reduction Achieved During Indicated Time Period							
2002-2010	18%	8%	19%	1%	1%	1%	1%
2011-2020	38%	40%	38%	27%	27%	27%	27%
2021-2030	44%	52%	43%	73%	73%	73%	73%

its much larger target fleet and, hence, larger magnitude of gasoline gallons avoided. However, the Fuel Efficient Tires option provides only a fraction of the emissions reduction achieved by the Group 1A Options.

Like the Group 1 options, the LDV Fuel Displacement (Group 2) options presented in Table 2-11 assume that VMT would not change relative to baseline vehicle operation. For these options, gasoline is displaced with alternative-fueled or a blend of alternative fuel and gasoline. In some cases, the alternative fuel vehicle can incur more emissions than are displaced, either from consuming more fuel due to a drop in energy content per gallon, or due to a larger emission factor for the alternative fuel. For these cases, such as with LPG and the ethanol blends, the fuel displacement option results in a negative emissions reduction — that is, net emissions increase — for certain criteria pollutants.

Even though the VMT would not change within each of these options, the Group 2 emissions reductions depend on both fuel cycle and vehicle operation. The emission factors for baseline vehicle operation may differ from those of alternative fuel vehicle operation. Thus, a vehicle tailpipe emission reduction may exist for a given option even though the VMT is the same for both the baseline and alternative fuel vehicles.

For the LDV Fuel Displacement options, the Electric Vehicles and the Grid-Connected Hybrids options provide the largest emission reduction. The hydrogen and methanol FCV options also provide significant emission reduction benefits, especially for CO. In fact, these four fuel displacement options provide larger NO_x and CO emission reduction benefits than those offered by the Group 1 options. However, the GHG reductions for these options are smaller than the Group 1A options, and similar to the Other Fuel Efficiency options.

The HDV Fuel Displacement options presented in Table 2-12 also assume that VMT would not change relative to baseline operation. For these options, diesel is displaced with natural gas or a reformulated diesel-alternative fuel blend. Due to the energy penalty in B20 relative to RFD, the B20 option consumes slightly more alternative fuel on an energy basis, and incurs slightly more PM compared to the baseline diesel HDV due to the increased upstream emissions associated with fuel distribution. Likewise, the CNG options also consume more fuel on an energy basis, and thus incur greater PM emissions. Again, this is associated with the upstream emissions and, in this case, is due to increased particulate emissions from electricity generation needed for compression.

FT Diesel provides the greatest criteria pollutant reduction among these options, but also is the only option in Groups 1 through 3 with a GHG penalty. In contrast, the B20 option provides the largest criteria pollutant penalty, but also provides the largest GHG reduction of all the Fuel Displacement options. However, each of the HDV blended fuel options assumes full penetration into the HDV market – that is, assumes that the entire on-road HDV diesel supply in California is displaced with the blended fuel. When taken together, the HDV natural gas options provide NMOG and Toxics reductions comparable to those provided by the FT option. Yet, the natural

Table 2-11. Estimated Emissions Reductions in 2002-2030 for LDV Fuel Displacement Options (tons)

Emissions Reduction	Fuel Cells (Gasoline)	Fuel Cells (Hydrogen)	Fuel Cells (Methanol)	Electric Battery Technologies	Grid Connected Hybrids	CNG for LDVs	LPG for LDVs	Alcohol Fuels in FFVs (E85)	Alcohol Fuels in FFVs (E65)	E10 (Ethanol Blend)	Light-Duty Diesel Vehicles (1.45x)
NO_x	202	8,568	8,290	14,227	10,661	889	-2,804	-2,351	-1,372	-1,731	291
CO	159	138,060	139,043	207,122	153,375	-1,858	-603	-670	1,970	-353	192
NMOG	3,112	19,181	15,375	29,979	24,229	27,890	-957	-4,119	-2,018	-198	19,145
Toxics	34	267	216	412	327	49	-84	156	155	83	-1,177
Particulate Matter	11.9	441	688	-912	-667	-249	-5	-39	-13	-13	-4,416
Greenhouse Gases (million tons)	60	96	73	159	157	28	47	73	70	126	62
Fraction of 2002-2030 Emissions Reduction Achieved During Indicated Time Period											
2002-2010	0%	0%	0%	0%	0%	0%	0%	0%	0%	11%	0%
2011-2020	11%	11%	11%	21%	21%	21%	21%	21%	21%	41%	21%
2021-2030	89%	89%	89%	78%	78%	78%	78%	78%	79%	47%	78%

Table 2-12. Estimated Emissions Reductions in 2002-2030 for HDV Fuel Displacement Options (tons)

Emissions Reduction[a]	CNG in Class 3-6 MDVs	CNG in Class 7-8 HDVs	LNG in Class 7-8 HDVs	FT Diesel (33%)	Biodiesel (2%) Diesel Substitution	Biodiesel (20%) Diesel Substitution
NO_x	10	64	-32	74	-330	-2,753
CO	-24	-168	-14	71	-66	-567
NMOG	98	620	7	829	-26	-402
Toxics	121	403	400	875	-10	-84
Particulate Matter	-3	-22	-1	5	-1	-9
Greenhouse Gases (million tons)	0	1	1	-23	16	127
Fraction of 2002-2030 Emissions Reduction Achieved During Indicated Time Period						
2002-2010	2%	2%	2%	1%	11%	2%
2011-2020	33%	33%	33%	35%	41%	40%
2021-2030	65%	65%	65%	64%	48%	58%

[a]HD options are compared to an HD diesel baseline vehicle.

gas options achieve these reductions while assuming a more modest market penetration than the HDV blended fuel options.

The Pricing options presented in Table 2-13 do incorporate VMT changes due to changes in driving behavior. Although the Feebates options incur additional VMT — thus generating greater NO_x and CO emissions relative to the baseline — they also encourage the purchase of fuel-efficient vehicles, and together invoke the greatest GHG reductions of the Pricing options. These Pricing options are assumed to apply to the entire state vehicle population. As a result of this large applicability, the Pricing options provide reductions of the same order of magnitude as the Group 1A options and the best of the Group 2 options.

Emissions reductions were estimated for the Other (Group 4) Petroleum Reduction options as well. The Group 4 estimates, although very rough, provide an order of magnitude estimate of potential emission reductions for such measures. Relative to the reductions estimates for Groups 1 through 3, the Land Use Planning options offer the most significant potential emission reduction. The Land Use Planning (10 percent VMT Reduction) option offers an estimated criteria pollutant reduction of about 340,000 tons in 2002-2030, most of which is due to CO reductions. The Land Use Planning (3 percent VMT Reduction) option offers an estimated criteria pollutant reduction of about 100,000 tons in 2002-2030, most of which is due to CO reductions.

The Increased Public Transit option in Group 4 also offers some criteria pollutant emission reduction on the order of 20,000 tons in 2002-2030. Given the fuel use and mileage estimates from the Task 3 Report, there is a NO_x and PM emissions penalty associated with this option. However, this analysis displaces driving light-duty PZEV vehicles (the baseline) with heavy-duty natural gas and electric transit buses, so the emissions reduction depends heavily upon the estimated future ridership due to implementing this option.

The other Group 4 options (Telecommuting, Reducing Speed Limits, and Voluntary Accelerated Vehicle Retirement) each provide a relatively small emission reduction in the 2002-2030 timeframe, with Telecommuting providing about 16,000 tons, most of which is from CO reduction. The Reduced Speed Limits option does not provide substantial criteria pollutant emissions reduction (about 5,300 tons in 2002-2030), but does provide about 92 million CO_2 equivalent tons of GHGs in the 2002-2030 timeframe. Under this analysis, the Voluntary Accelerated Retirement option provides an emissions penalty during all phases of the option, as it is assumed that the vehicles in this option are driven more than usual prior to retirement. However, in keeping with the standard analysis methodology, the Voluntary Accelerated Early Retirement option was applied to PZEV baseline vehicles. Presumably, in practice much older vehicles with greater emissions would be the target of this option.

Table 2-13. Estimated Emissions Reductions in 2002-2030 for Pricing Options (tons)

Emissions Reduction	Gasoline Tax	Pay-at-the-Pump Auto Insurance	Pay-as-You-Drive Auto Insurance	VMT Tax	Statewide Feebates	Nationwide Feebates	Registration Fee Transfer	Purchase Incentives
NO_x	10,861	8,822	8,428	8,857	-423	-4,150	1,741	93
CO	165,929	134,557	131,432	138,019	-21,029	-108,929	26,544	73
NMOG	26,588	21,789	18,245	19,257	11,958	30,452	4,306	1,430
Toxics	358	293	254	267	120	281	58	15
Particulate Matter	882	716	688	723	-57	-407	141	5
Greenhouse Gases (million tons)	284	235	170	180	263	748	46	28
Fraction of 2002-2030 Emissions Reduction Achieved During Indicated Time Period								
2002-2010	24%	24%	25%	25%	3%	5%	24%	10%
2011-2020	35%	35%	35%	35%	31%	33%	35%	38%
2021-2030	41%	41%	40%	40%	66%	62%	41%	52%

3. Value of Emission Reductions and Other Possible Economic Benefits

The previous chapter estimated the emissions reductions possible for each of the petroleum reduction options analyzed. In this chapter we present the methodology for estimating the benefits of the emission changes associated with the various petroleum reduction options. This section focuses on the valuation or $/ton estimates. Section 4 estimates the monetary value of the possible environmental and economic impacts of reducing petroleum use by combining the results of Section 2 with the results of this section. We discuss first the concept of estimating the damages associated with environmental pollution in Section 3.1. This is followed in Section 3.2 with the methodology and valuations used in this study to determine monetary damages per ton for criteria pollutants and water pollution. Section 3.3 discusses in more detail our assessment methodology for evaluating the human health benefits of reducing fine particulate ($PM_{2.5}$) emissions. Water pollution benefits are addressed in Section 3.4 and global warming issues addressed in Section 3.5. Finally, economic impacts are discussed in Section 3.6.

The purpose of this chapter is to explain how we estimated the value of emissions changes and to provide the results of our analyses. We also have tried to place the results of the analyses in context with the uncertainties of estimating benefits of reducing petroleum by comparing our results to similar recent analyses on valuing emission reductions performed for the U.S. and for Europe.

3.1 Estimating Damage Costs Associated with Environmental Pollution

We estimated the amount of emission reductions that result from various petroleum reduction options. These estimates tracked the volumes of fuel that moved from resource extraction to end-use in the vehicle. Emissions were estimated along each part of fuel production, distribution, and use depending on the pollutant. However, some simplifying assumptions were made on extraction and refinery emissions for criteria pollutants such as NO_x. In these cases, we counted only the emissions that occur in California and not those criteria pollutant emissions that occur in refineries located outside of California. Greenhouse gas emissions were estimated for the total fuel chain from extraction to end-use. We defined our boundary conditions in this way, in part, because of our baseline assumption: except for improvements in refinery processes, any additional demand for petroleum products in California will have to be met either by importing refined products or blend stocks, by displacing the demand by alternative fuels, or by reducing the demand with more efficient vehicles.

The overall objective of this project was to determine the possible value of reducing California's petroleum dependency. We chose a cost-benefit analysis to assess the possible value of various options. The non-environmental net benefits were estimated in a separate analysis, and these results are presented in Appendix C (California Energy Commission 2002) of this report series. One objective of this report was to estimate the environmental net benefits and the possible economic benefits associated with the various petroleum reduction options.

This section describes the commonly accepted methodology for estimating the value of emission reductions. Most of this discussion is taken from Section 7 of the U.S. Environmental Protection Agency's (EPA's) *OAQPS Economic Analysis Resource Document*, (U.S. EPA 1999b) and the interested reader is referred to this reference for more information on cost-benefit analyses. The benefits of emissions reduction consist of the effects that an improvement in environmental quality has on human welfare. The question we were trying to answer was: What damages do the emissions associated with the production, distribution, and use of petroleum or spills of product cause to human and animal health, agriculture, forests, water quality, and visibility? Individuals derive satisfaction (referred to in economic terms as utility) from the services provided by the natural environment. To the extent that improvements in the quality of the natural environment improve the service flow provided to humans, individuals experience a utility gain. Conversely, any damage to the physical environment that decreases the quantity or quality of these service flows results in a utility loss. In this context, the natural environment can be viewed as a natural asset, the services of which include such things as life support for humans and other living things, as well as visual amenities. Changes in the environment that result from pollution hinders nature's ability to provide such service flows to humans.

Figure 3-1 shows the relationship between emission reductions and value of emission reductions. A similar chart could also be made for water pollution. In a larger analysis this would be the procedure to estimate the value of emissions. One would first estimate the emissions inventory of the baseline case from which exposures could be determined with fate and transport models. A petroleum reduction option could then be analyzed to determine the reduction in emissions and the corresponding reduction in exposure. Once the reduction in exposure is determined, the changes in environmental service flows could be calculated followed by estimates of the costs of these changes in service flows.

3.1.1 Damages

In the context of assessing petroleum dependency, we have used the traditional definition of benefits. Benefits are reductions in damages to environmental service flows attributable to the petroleum reduction option. Damages can be avoided by using less petroleum as a result of a decrease in upstream distribution emissions or as a result of fewer emissions of GHG. Categories of damages can be group into three broad areas:

A. Direct damages to humans, including health damages and aesthetic damages

- Health damages result from human exposure to pollutants. These damages include increases in the risk of death (mortality risk) and increases in the risk of experiencing an adverse health effect (morbidity risk). Adverse health effects can be divided into acute effects, such as headaches or eye irritation, which generally last only a few days, and chronic effects, such as emphysema or asthma, which are generally associated with long-term illness.

- Aesthetic damages result from contamination of the physical environmental and include increased problems of odor, noise, and poor visibility.

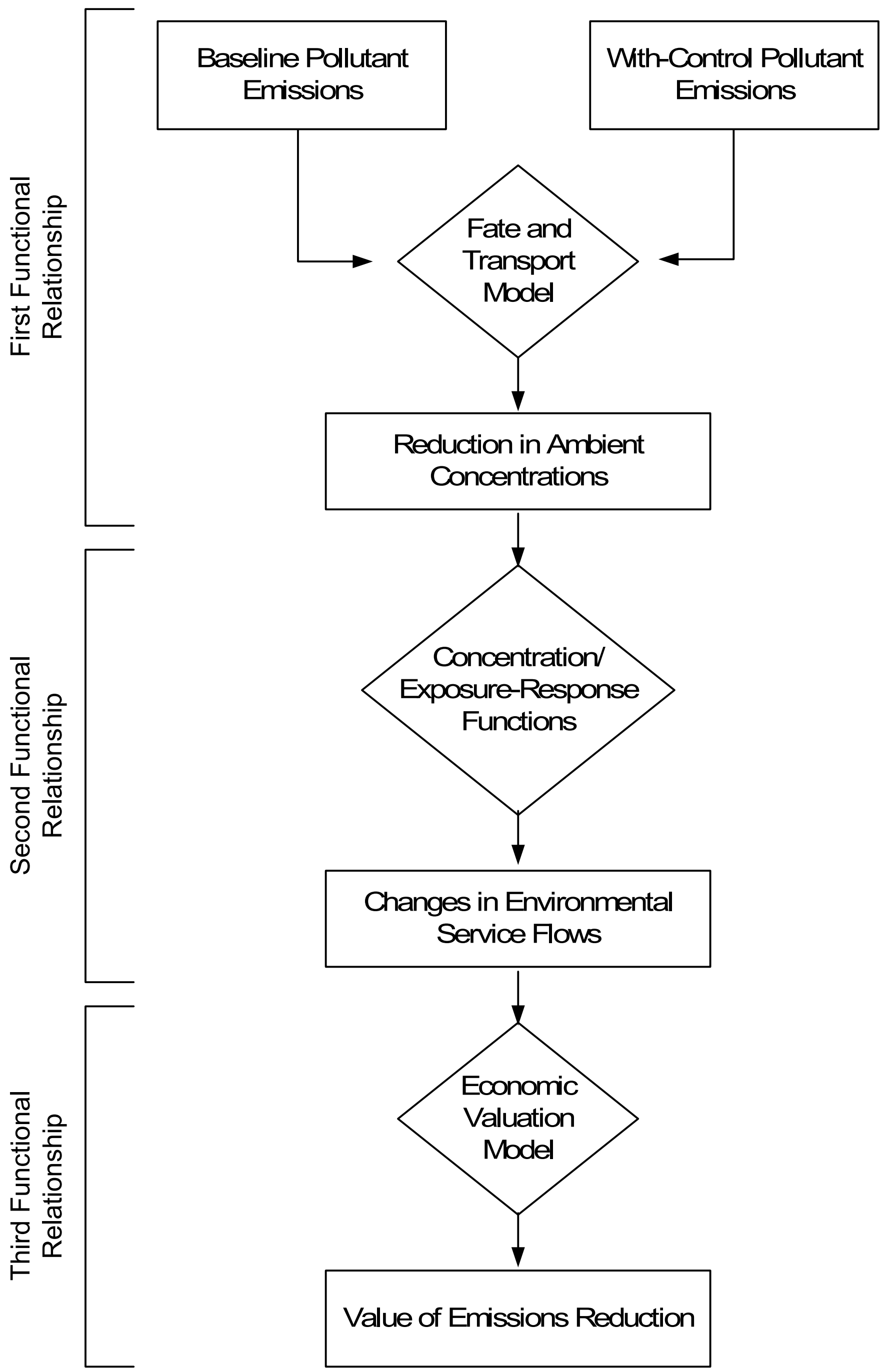


Figure 3-1. Functional Relationships in Benefits Analyses

B. Indirect damages to humans through ecosystems, including productivity damages, recreation damages, and intrinsic or nonuse damages.

- Productivity damages, including reduced productivity of farmland, forests, and commercial fisheries, result from pollution damages to physical environments, which support these commercial activities.
- Recreation damages result from the reduced quality of environmental resources such as oceans, lakes, and rivers used for recreational activities.
- Intrinsic or nonuse damages include losses in the value people associate with preserving, protecting, and improving the quality of ecological resources that is not motivated by their own use of those resources.

C. Indirect damages to humans through nonliving systems, including damages to materials and structures (e.g., buildings and equipment) that are caused by pollution and which can reduce the productivity of these assets.

3.1.2 Emissions and Exposure

For petroleum reduction options, the emission impacts needed to be estimated. In most cases, petroleum reduction options reduce emissions compared to the baseline; however, in some instances emissions increase. Either way these need to be assessed. The next step is to estimate the exposures based on the emissions comparison of the option compared to the baseline case. This can become very complicated, as illustrated in Figure 3-2. Shown in the figure are the possible mechanisms for changes in ambient concentrations and service flows associated with changes in sulfur oxides (SO_x), NO_x, and volatile organic compounds (VOCs). Not only are there direct effects of pollution on human health, there are also many indirect effects. For example, NO_x and VOCs are precursors to ozone formation. NO_x also interacts with ammonia and other atmospheric gases to form secondary particulate. Both pathways affect human health. Many of the interactions shown in Figure 3-2 are nonlinear. The modeling of all these various interactions is extremely complicated, time-consuming, and costly.

The U.S. EPA and others have conducted extensive analyses and studies to quantify the health effects of air pollution (e.g., U.S. EPA 1999). Generally they have, for each health effect or so-called “end point,” identified a dose-response or concentration-response relationship. This relationship is a function of changes in ambient concentration and population exposed to the concentration. Typical results are expressed in number of avoided cases as a result of the change in concentration. Similar assessments can be made for estimating ecological and nonliving system impacts. Concentration-response relationships are used to estimate the effects of ground-level ozone on agriculture and forests, for example. Exposure to pollution accelerates damages to many materials and architectural coatings. Estimates of these damages are again assessed from relationships of concentration or exposure and degradation.

The final step in determining the benefits is to monetize the quantitative estimates of changes in environmental service flows. This is done by estimating society’s willingness to pay (WTP) for a given benefit. WTP is the maximum amount an individual is willing to pay to acquire a

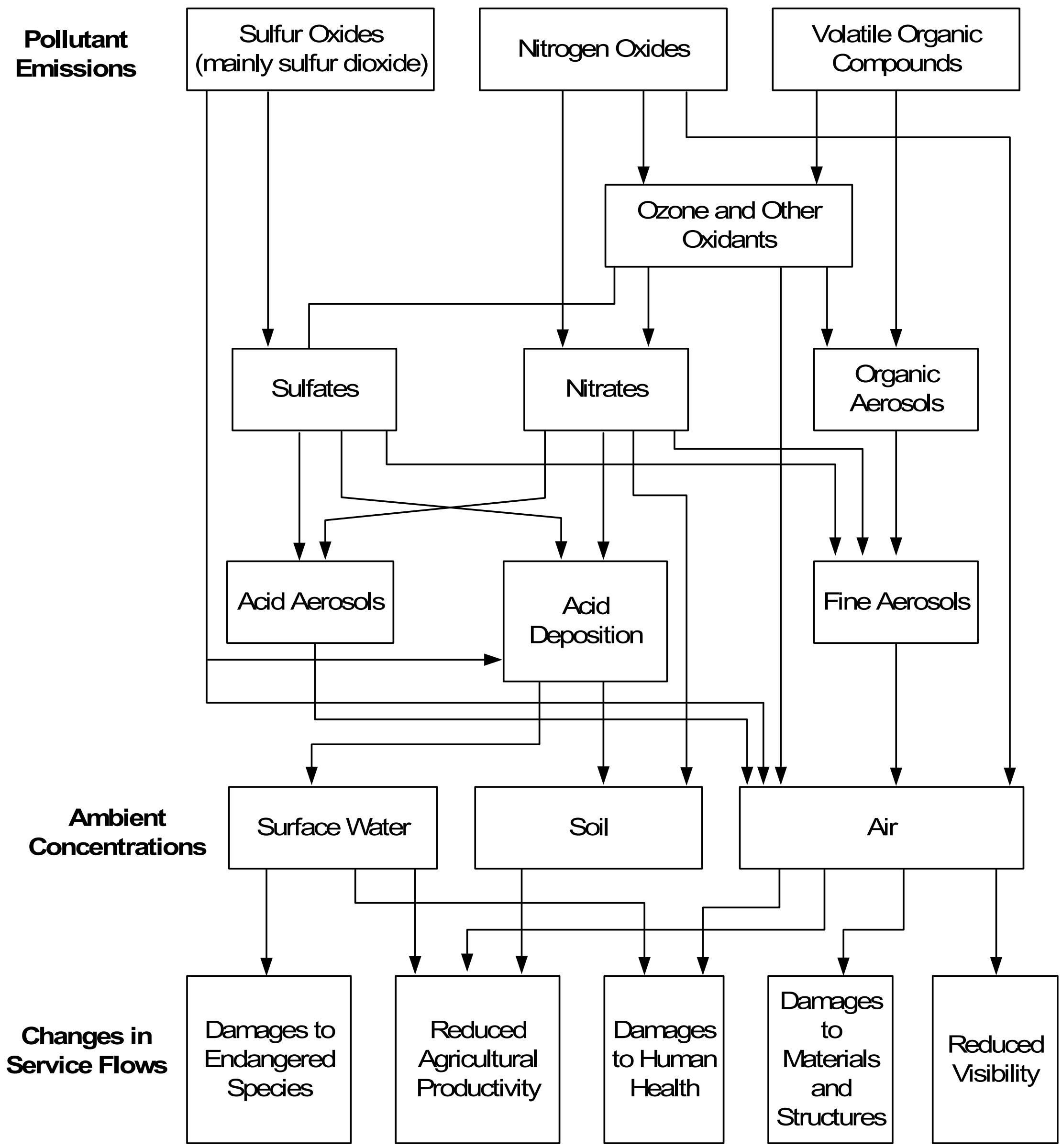


Figure 3-2. Relationships between SO_x, NO_x, and VOC Emissions and Ambient Concentrations and Changes in Service Flows

benefit. It is measured as the reduction in income required to return an individual to the level of utility he or she enjoyed prior to receiving the benefit.

3.1.3 Monetizing Benefits

Economists use different techniques to monetize various health benefits. For nonfatal illness and injury (morbidity) four different approaches are used: cost of illness, expressed preference methods, averting action methods, and hedonic wage and property value methods. Cost of illness (COI) is most often used in economic analyses of human health effects. The COI approach for morbidity measures the direct and indirect costs resulting from a health effect. Direct costs include such things as the value of goods and services used to diagnose and treat individuals suffering from the health effect. Indirect costs consist primarily of foregone productivity measured by lost wages. COI does not account for the full range of costs associated with an illness or injury. Pain and suffering, for example, are not included in these estimates. Therefore, the results of COI analyses should be considered as lower-bound estimates of society's WTP for reductions in such risks. See U.S. EPA 1999b for further discussion on WTP for morbidity.

Reduction in emissions may also result in a reduction in fatalities or reductions in the risk of premature death. Again, the U.S. EPA and the economics literature have extensively addressed the relationship of monetizing the benefits of reduced or avoided cases of premature death (mortality). The value of a statistical life (VSL) is the usual measure used to determine the monetary value of an avoided death. VSL is easily misinterpreted, and probably some other nomenclature should be used. Nevertheless, VSL refers to the WTP for reductions in the risk of premature death aggregated over the population experiencing the risk reduction. This concept is fairly well accepted by EPA and economists, and is generally expressed as a single number. The range of numbers in the literature varies from $3 million to $7 million. EPA has used a number of about $6 million.

Values for ecological benefits and benefits to materials and structures are estimated using a variety of techniques, including hedonic property value models, travel cost models, expressed preference methods, and market models. Hedonic property value models can be used to estimate the value individuals and households place on the perceived amenity and recreation benefits provided by the property. Travel cost models estimate the benefits of environmental improvements to recreators. For example, these models can be used to estimate anglers' WTP to reduce toxic contamination of a water body that otherwise would be subject to a fish consumption advisory.

EPA and others have developed an extensive literature base for estimating the costs of human morbidly and mortality as well as the costs of ecological damages and damages to materials and structures. These valuations seem to be fairly robust and have been used in a number of recent studies by EPA and others. See for example EPA's recent analysis of the Clean Air Act (U.S. EPA 1999a) and EPA's analyses of the heavy-duty standards and fuel sulfur regulation (U.S. EPA 2000).

In summary, the values of emissions associated with various petroleum reduction options are determined by first estimating the change in emissions and then determining the change in ambient concentrations. Effects on human health and other ecosystems are estimated from dose-response or concentration-response relationships which themselves are functions of population or area affected. Economists have then estimated society's willingness to pay for mortality and morbidity as well as improvements in ecology and to materials and structures. The methodology is comprehensive and attempts to quantify all the possible effects of pollution on our natural environment. However, the resources and time necessary to undertake such a comprehensive analysis were well beyond the scope of the present petroleum dependency assessment, especially considering the number of different options considered.

3.2 Methodology for Estimating Environmental Benefits of Petroleum Dependency

Because it was beyond our scope to perform detailed analyses for each possible petroleum reduction option considered in this analysis, we tried to look for monetary estimates of emissions that could be expressed as monetary damages per ton of pollutant. This would be the easiest to implement since we had, for each option, emission estimates for criteria pollutants, toxic pollutants, and GHG as well as change in volume of petroleum or liquid fuels used.

To obtain these monetary estimates, we reviewed previous studies and assessments that estimated damages either in dollars or in dollars/ton. Termed "benefits transfer," this approach, although time saving, also has many possible flaws (U.S. EPA 1999b). First, the emission reductions need to be comparable so that the changes in concentrations will be similar. Second, the population exposed also needs to be similar. Finally, the time value of money needs to be adjusted base on the currency dollars used in the analysis. If the study or assessment presents the results in dollars, there is often reported the emission reductions associated with the reported benefits. However, this too can be inaccurate as often only the direct emissions are reported, and secondary emissions as a result of the direct emissions and reactions in the atmosphere are usually not reported. Thus, normalizing the reported benefit by the direct emissions only is problematic.

Even with these caveats, using such a benefits transfer methodology was the only viable option given the constraints of time and resources. Also, because this was a comparative analysis, it was judged that the accuracy of individual valuations is less important than the aggregated results of the various options. It is reasonable to assume that values from the transfer methodology give a reasonable estimate of the value and that the comparative trends are in the right direction.

We performed a literature search to identify recent studies that might be appropriate for this study. We focused our search on studies that had used the full analysis described in the previous section. Table 3-1 summarizes the results of this review. As indicated, we identified four recent studies that estimated the benefits of reducing emissions from motor vehicles. All studies estimated the emissions reduction and corresponding changes in ambient concentrations followed by an assessment of the effect of this change on concentrations or exposure to human health and other ecosystems. The EPA study uses a common valuation of the health effects and other ecosystem damages, which is very similar to the European work by Friedrich and Bickel. Friedrich and Bickel modified some of the EPA valuations to match European conditions compared to those of the U.S. Delucchi and associates also performed similar analyses. They first assumed a 10-percent reduction in emissions from motor vehicles and then modeled the change in ambient concentration and exposure. Human health and other ecosystem damages were then calculated. Valuations of these damages were then used to determine total damages. As shown in Table 3-1, Delucchi (1998) estimated damages for human health, visibility, water pollution, crops, forests, and materials. This study was completed for various regions in the U.S. ranging from highly populated areas like Los Angeles to more rural areas. This study also provides estimates of damages on a $/ton basis. The European work (2001) also provides estimates on a $/ton basis but for specific examples of modeling that were complete. The EPA analyses (1997, 1999) estimate damages based on the direct emissions reduced or predicted to be reduced. Most of the EPA estimates are either for the U.S. or specific regions of the U.S.

Table 3-1. Literature on Monetizing Emission Benefits

Title of Work	Benefits Quantified	Reference:
Summary of the Nonmonetary Externalities of Motor-Vehicle Use	• *Health costs* for CO, NO_x, $PM_{2.5}$, PM_{10}, SO_x, VOC, VOC+NO_x (ozone) • *Visibility Costs* for PM_{10}, NO_x, SO_x, VOC • *Crop Market* for VOC+NO_x (ozone) • *Climate Change Costs* for CO_2 equivalent emissions • Marginal *Cost of noise* • *Costs of* motor vehicle related crimes • *Water pollution Costs* • *Costs of fires* related to motor vehicle use	Delucchi 1998
Environmental External Cost of Transport	• *Health related costs* for $PM_{2.5}$, PM_{10}, SO_x, CO, NO_x, Ozone • *Degradation of Building Materials* • *Cost of Climate Change*	Friedrich and Bickel 2001
Clean Air Act EIA pre 1990	• *Ozone*	U.S. EPA 1997
Clean Air Act EIA post 1990	• *Ozone*	U.S. EPA 1999a

Based on this review, we chose to use the analysis performed by Delucchi. This was done for the following reasons. First, the results were performed for vehicles used in the U.S. and Los Angeles, in particular. Second, the Delucchi results covered all the damages we wanted to estimate, whereas other studies included only one or two of the possible effects. Thus, Delucchi's results provided us with \$/ton valuations for a comprehensive list of damages. An additional benefit of using the Delucchi results is that we did not have to worry about inconsistencies in modeling approaches. This, at least, minimized the possibility of different modeling assumptions used by different analysts. That said, we also wanted to see how the results of these different studies compared. Our thought was if the results were comparable this would give us more confidence in using a "benefit transfer" type of analysis.

Delucchi makes the important distinction between the external costs of damages and those which may be internalized in the price of a product. Most of his estimates are for marginal changes in emissions rather than "average" changes. Unless otherwise identified in this discussion, the results presented here are for marginal changes in emissions.

Delucchi's results were reported in 1991 dollars and we assumed that populations were consistent with that year. Populations are important for estimating health effects because the effect is proportional to the population exposed. As a result, if the population doubles the damage associated with health effects also doubles. This may not be the case with other ecosystem damages like ozone damages to agriculture. We assumed that the population of crops or other elements of the ecosystem were unchanged. To adjust 1991 dollars to 2001 dollars, we used a Consumer Price Index ratio of 1.3. For population adjustments, we first adjusted the population to 1999 and then used the projected population growth of 1.4 percent for California to project to 2030 (Energy Commission 2001). This results in a population correction factor of 1.76.

Table 3-2 summarizes Delucchi's results factored up to 2001 dollars and 2030 population. Both Delucchi's low and high estimates are shown for either the Los Angeles region or the United States. For all health effects estimates, we used Delucchi's estimates for the Los Angeles region as most of the California population lives in nonattainment regions. However, one could argue that this possibly over-predicts the valuation of health effects since the highest exposures in the state generally occur in the Los Angeles area. Most of California's population is exposed to levels of pollution similar to that in the Los Angeles area and, therefore, in the aggregate using Delucchi's estimates should provide results representative of California as a whole.

Delucchi used the sum of NO_x+VOCs as the pollutants for ozone. Delucchi pointed out that at best this is only an approximation because ozone production is a highly complicated interaction of these pollutants with atmospheric conditions. Ozone formation is nonlinear and depends upon many variables, including the ratio of NO_x to VOCs. Nevertheless, as pointed out by Delucchi, using NO_x+VOCs is probably reasonable if the reductions in NO_x and VOCs do not deviate too far from their assumptions.

Table 3-2. Comparison of Emissions Valuations

Pollutant or Effect	Delucchi '01$+'30 population Low	Delucchi '01$+'30 population High	Region	Friedrich&Bickel Europe 2000	EPA Pulp&Paper RIA ('96$ to '01$)	Delucchi Low+High/2	Used In this Report 2001$/ton
Air Pollution							
CO	62	370	LA	21		216	220
NO_x (nitrate PM)	12,500	157,000	LA			84,700	
NO_x (NO_2)	1,000	5,500	LA	9,000.		3,200	
Total NO_x	13,600	163,00	LA			88,300	88,000
$PM_{2.5}$	133,000	1,615,000	LA	1,170,000		874,000	352,000
PM_{10}	79,000	162,000	LA		28,400	120,500	
SO_x	72,500	470,000	LA	20,900	11,006	271,300	
VOC	1,000	9,000	LA	800	5,805	5,000	5,000
VOC+NO_x	100	830	LA			465	460
Loss of Visibility	*2001$/ton*						
PM_{10}	670	6,200	US	included in above		3,400	3,400
NO_x	320	1,800	US			1,060	1,000
SO_x	1,500	6,300	US			3,900	3,900
VOCs	12	82	US			47	47
Water Pollution	*2001$/gal*						
Leaking UGT	0.00075	0.00373	US				
Oil Spills	0.00255	0.00638	US				
Urban Runoff	0.00149	0.00373	US				
Subtotal	0.00479	0.01383	US			0.009	0.009
Other Damages	*2001$/ton [NOx+VOC]*						
Agriculture	206	383	US			295	300
Materials	39	786	US			413	400
Forests	19	196	US			108	110

For all non-health-related effects, we used Delucchi's estimates for the United States. Marginal estimates are shown for visibility and the effects of pollution on agriculture. Delucchi estimated total costs of water pollution and pollution damages to materials and forests. For this analysis, these total costs were then normalized by the 1991 volumes of petroleum product used or by the summation of NO_x and VOCs reduced. This normalization is reasonably good for water pollution estimates but is less accurate for damages to materials and forests. In the case of damages to materials, ozone (NO_x +VOC) and PM cause damages, so by normalizing only by NO_x and VOC could misrepresent the valuation. We choose to neglect any further analysis of this as the valuations were fairly low in comparison to the human health damages.

Delucchi did not report estimates of damages resulting from toxic emissions. This is discussed further in the following section.

Also shown in Table 3-2 are estimates made by others of various damages. Two studies are shown. As indicated earlier each of these studies used the same methodology to estimate damages. Friedrich and Bickel provided several estimates of damages depending on the region in Europe and the assumed reduction in transportation emissions. The results shown here were taken from an analysis for France of the tailpipe emissions for various gasoline and diesel technologies in g/km from which damage costs in Euro/km were determined. Damage costs in Euro/g or $/ton could be estimated from these results (see Table 13.6, page 178, of Friedrich and Bickel 2001). No correction was made to these estimates for value of money (assumed Euro to dollar of 1:1) or for population exposures. These estimates were also similar to estimates for other regions in Europe provided in this reference.

The EPA estimates are also shown for comparison. The comparison is from the EPA Pulp and Paper Regulatory Impact Analysis (RIA) (these results were taken from U.S. EPA 1999b). The numbers from this reference were adjusted to 2001 dollars and the population exposure increase reflects 2030.

We chose to use the average of Delucchi's low and high to values for the emission damages. The one exception was for the damages associated with fine particulate, $PM_{2.5}$. Our methodology for estimating the damages for this pollutant is discussed in the next section.

3.3 Estimating Damages for $PM_{2.5}$ and Toxic Emissions

The damage estimates for $PM_{2.5}$ are considerably higher than for other pollutants due mostly to premature deaths (mortality). Fine particulate is believed to cause a host of health-related problems, including premature deaths and increased hospitalization admissions and emergency room visits, primarily in the elderly and individuals with cardiopulmonary disease; increased respiratory symptoms and disease, in children and individuals with cardiopulmonary disease such as asthma; decreased lung function, particularly in children and individuals with asthma; and alterations in lung tissue and structure and in respiratory tract defense mechanisms. The largest of these damages is for premature death and this is usually estimated on the willingness to pay for a change in the risk of death. Mortality damages exceed morbidity damages by an order of magnitude or more.

The objective of this section, then, is to review our methodology for determining $PM_{2.5}$ health damages and to discuss why we chose not to value toxic emissions. The first part of this section discusses $PM_{2.5}$.

3.3.1 $PM_{2.5}$ Health-Based Damages

Because the health damage estimates for $PM_{2.5}$ are much higher than for other pollutants, the ARB performed an independent assessment of the damages for this effort. The ARB used the California Criteria Air Pollutant Modeling System (CalCAPMS) to estimate PM health effects in California. The objective of this analysis was to estimate damages associated with $PM_{2.5}$ on a cost-per-ton basis.

The CalCAPMS model is a population-based system for determining exposures to criteria air pollutants and estimating health benefits. The model reads in air quality monitoring data and rolls back $PM_{2.5}$ concentration levels at a specific fraction to a threshold or background concentration. The model divides California into eight kilometer by eight kilometer grid cells, applies selected health effects studies, and estimates the changes in incidence of adverse health effects associated with given changes in air quality in each grid cell. The incidence change for the state or individual counties is then calculated as sum of grid-cell-specific changes. The monetary value of a change in the incidence of a given adverse health effect is then calculated. The model is a California version of CAPMS developed by ABT Associates. The CAPMS has been the primary model used by the U.S. EPA for air pollution health effects analyses including Section 812 – the Benefits and Costs of the Clean Air Act and the RIA Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (U.S. EPA 1997, 1999a, and 2000).

A substantial number of published epidemiological health studies have shown that inhaled PM poses a hazard to human health. Specifically, the studies have shown evidence of a variety of PM-related health effects, ranging from minor symptoms, to hospitalizations for respiratory and cardiovascular disease, emergency room visits, chronic illness, and premature mortality. In the past few years, the U.S. EPA has embarked on several significant efforts to quantitatively assess the health effects associated with exposure to ambient PM. The U.S. EPA Section 812 reports to the Congress (U.S. EPA 1997 and U.S. EPA 1999a) included comprehensive analyses of the health benefits of the Clean Air Act. These reports have undergone years of public review and comment as well as full peer review by the independent Science Advisory Board. A year after the submission of the report to the Congress, U.S. EPA released its regulatory impact analysis on Heavy-duty engine/diesel fuel rule (U.S. EPA 2000). Recently, the ARB approved the amendments to the standards for PM and sulfates based on its staff recommendations as well as recommendations from staff with the Office of Environmental Health Hazard Assessment. The health effects associated with PM were quantified in the staff report (CARB 2002b). The report was reviewed by the public and the Air Quality Advisory Committee, an external scientific peer review committee comprised of world-class scientists in the PM field.

In light of the substantial reviews of studies quantifying the benefits of controlling PM, we have drawn considerably from prior efforts, particularly in the development of concentration-response functions and the corresponding economic valuations. To the extent possible, we selected the best available studies with the most conservative estimates. For example, for long-term exposure mortality, we selected Krewski's study (Krewski 2000) which has the smallest coefficient among the long-term exposure studies (Pope 1995, Dockery 1993, and Pope 2002). The unit monetary values are the same as those used in the U.S. EPA primary benefits analyses for all health endpoints except hospital admissions. The unit monetary values for hospital admissions were based on more recent California hospitalization cost data. All studies selected for this analysis and corresponding monetary values are further discussed in Appendix E of this report.

One important issue is whether to apply a threshold below which there are no detectable health effects when estimating the PM health effects in the model. To date there is no clear evidence on whether there is a threshold of PM, and at what level if there is one. Due to a lack of scientific evidence, U.S. EPA did not apply a threshold either in the Section 812 or the Heavy-duty engine/diesel fuel rule analyses. In this analysis, however, ARB did apply thresholds primarily for the reason of being conservative. The estimated natural background of 4.55 $\mu g/m^3$ for $PM_{2.5}$ (CARB, 2002a) was applied for all health end points. This estimated natural background is based on $PM_{2.5}$ observations at Point Reyes National Seashore which is located away from populated areas. This location, however, is not isolated from human activities. The PM concentration levels at this location are therefore higher than the true natural background PM levels. Consequently, applying this estimated threshold may underestimate the health effects associated with PM generated by human activities.

The CalCAPMS model requires an estimate of the percent change in particulate matter concentrations to calculate the damages associated with each health endpoint on a population-weighted basis through the use of a grid that divided California into eight-by-eight kilometer cells as previously discussed. For the damage estimates presented in this section, the CalCAPMS model was used to estimate the health benefits associated with a 10 ton/day reduction in $PM_{2.5}$ emissions which translates into a 0.78 percent reduction in the direct $PM_{2.5}$ concentration for each data point in the model that exceeds the natural background of 4.55 $\mu g/m^3$.

The health and monetary benefits presented in Tables 3-3 through 3-5 are based on a 0.78 percent reduction in the concentration of $PM_{2.5}$ for each data point in the model above the natural background of 4.55 $\mu g/m^3$. The 0.78 percent reduction in concentration was derived from dividing 10 tons/day (the surrogate emission reduction used for this example) by 761 tons/day (the annual average Statewide direct emissions of $PM_{2.5}$) resulting in a factor of 0.013 (10 tpd/761 tpd) which was then multiplied by 60 percent (i.e., 0.013 x 0.6 = 0.0078) resulting in 0.78 percent.

The purpose of the 60 percent multiplier is to exclude secondary or indirect $PM_{2.5}$ (e.g., $PM_{2.5}$ formed from emissions of oxides of nitrogen, sulfur oxides, and volatile organic compounds) from our analysis as the impact of indirect $PM_{2.5}$ is addressed in a subsequent section of this report. The approach used here assumes that 40 percent of the $PM_{2.5}$ measured in the ambient air is attributed to indirect formation rather than direct emissions. Depending upon such factors as location and timeframe, previous studies document a broad range in the percent of $PM_{2.5}$ associated with indirect emissions (NARSTO, 2003). Generally, data tend to support the assumption that the percentage of $PM_{2.5}$ attributable to indirect emissions on an annual basis falls between a range of about 40 to 50 percent in several regions of the State. Therefore, 40-percent

Table 3-3. Annual PM-related Health Benefits in 2010 — (Reduction of 10 tons $PM_{2.5}$/day)

Health Endpoint	Reference	Avoided Incidence (cases/year)			Monetary Benefits (1999$)		
		5th Percentile	Mean	95th Percentile	5th Percentile	Mean	95th Percentile
Mortality							
Long-Term Exposures Mortality							
Ages 30+	Krewski et al., 2000	82	143	205	103,073,368	875,792,108	1,299,823,232
Chronic Illness							
Chronic Bronchitis (Age 27+)	Abbey, 1995	20	127	235	6,390,192	42,091,918	77,680,200
Hospitalization							
COPD (ICD codes 490-492, 494-496), Age 65+	Samet et al., 2000	3	15	25	52,764	256,241	459,798
Pneumonia (ICD codes 480-487), Age 65+	Samet et al., 2000	11	20	29	234,959	435,934	636,942
Cardiovascular (ICD codes 390-429), Age 65+	Samet et al., 2000	29	35	40	887,917	1,047,186	1,206,459
Asthma (ICD codes 493), Age 64-	Sheppard et al., 1999	3	10	17	33,686	107,408	181,152
Asthma-related ER Visits, Age 64-	Schwartz et al., 1993	18	42	66	6,958	12,543	21,425
Minor Illness							
URS, Age 9-11	Pope et al., 1991	1,322	4,203	7,084	37,362	101,822	239,280
LRS, Age 7-14	Schwartz et al., 1994	2,061	4,371	6,676	14,968	66,870	135,849
Asthma Attacks, All ages	Whittemore and Korn, 1980	1,285	3,521	5,758	52,411	143,674	234,923
Work Loss Days	Ostro, 1987	26,662	30,601	34,539	2,821,490	3,238,301	3,655,063
Total						***923,294,005***	

$/Ton ($99)	252,957
$/Ton ($01)	266,905

Table 3-4. Annual PM-related Health Benefits in 2020 — (Reduction of 10 tons $PM_{2.5}$/day)

Health Endpoint	Reference	Avoided Incidence (cases/year)			Monetary Benefits (1999$)		
		5th Percentile	Mean	95th Percentile	5th Percentile	Mean	95th Percentile
Mortality							
Long-Term Exposures Mortality							
Ages 30+	Krewski et al., 2000	93	163	233	109,115,312	997,878,966	1,479,331,968
Chronic Illness							
Chronic Bronchitis (Age 27+)	Abbey, 1995	22	146	269	7,334,432	48,311,443	89,158,016
Hospitalization							
COPD (ICD codes 490-492, 494-496), Age 65+	Samet et al., 2000	4	19	35	74,042	359,573	645,217
Pneumonia (ICD codes 480-487), Age 65+	Samet et al., 2000	15	28	40	329,708	611,728	893,794
Cardiovascular (ICD codes 390-429), Age 65+	Samet et al., 2000	41	49	56	1,245,978	1,469,472	1,692,973
Asthma (ICD codes 493), Age 64-	Sheppard et al., 1999	3	11	18	37,454	119,422	201,415
Asthma-related ER Visits, Age 64-	Schwartz et al., 1993	20	47	73	5,462	13,946	27,831
Minor Illness							
URS, Age 9-11	Pope et al., 1991	1,495	4,752	8,010	40,584	115,127	186,263
LRS, Age 7-14	Schwartz et al., 1994	2,316	4,912	7,503	38,948	75,149	140,985
Asthma Attacks, All ages	Whittemore and Korn, 1980	1,466	4,018	6,570	59,807	163,947	268,071
Work Loss Days	Ostro, 1987	29,230	33,548	37,866	3,093,294	3,550,248	4,007,155
Total						***1,052,669,021***	

$/Ton ($99)	288,402
$/Ton ($01)	304,483

Table 3-5. Annual PM-related Health Benefits in 2030 — (Reduction of 10 tons $PM_{2.5}$/day)

Health Endpoint	Reference	Avoided Incidence (cases/year)			Monetary Benefits (1999$)		
		5th Percentile	Mean	95th Percentile	5th Percentile	Mean	95th Percentile
Mortality							
Long-Term Exposures Mortality							
Ages 30+	Krewski et al., 2000	108	189	270	144,992,144	1,155,400,219	2,285,670,400
Chronic Illness							
Chronic Bronchitis (Age 27+)	Abbey, 1995	25	166	307	8,361,504	55,076,531	101,642,568
Hospitalization							
COPD (ICD codes 490-492, 494-496), Age 65+	Samet et al., 2000	6	27	49	104,173	505,900	907,787
Pneumonia (ICD codes 480-487), Age 65+	Samet et al., 2000	21	39	57	463,882	860,670	1,257,523
Cardiovascular (ICD codes 390-429), Age 65+	Samet et al., 2000	58	69	79	1,753,026	2,067,471	2,381,926
Asthma (ICD codes 493), Age 64-	Sheppard et al., 1999	4	12	20	41,362	131,882	222,431
Asthma-related ER Visits, Age 64-	Schwartz et al., 1993	22	52	81	7,619	15,402	30,735
Minor Illness							
URS, Age 9-11	Pope et al., 1991	1,825	5,802	9,778	73,724	140,542	182,778
LRS, Age 7-14	Schwartz et al., 1994	7,822	5,985	9,143	29,000	91,574	157,565
Asthma Attacks, All ages	Whittemore and Korn, 1980	1,649	4,604	7,527	68,517	187,823	307,111
Work Loss Days	Ostro, 1987	31,173	35,778	40,383	3,298,898	3,786,223	4,273,497
Total						***1,218,264,237***	

$/Ton ($99)	333,771
$/Ton ($01)	352,381

was chosen for this analysis as it is expected to roughly approximate the $PM_{2.5}$ concentration attributable to direct emissions. Assuming that 50 percent of the $PM_{2.5}$ concentrations on an annual basis are attributable to indirect emissions would yield cost-per-ton estimates that are about 20 percent lower than those presented in Tables 3-3 through 3-5.

3.3.2 Valuation of Toxic Emissions

Although we have estimates of the toxic emissions reductions associated with various petroleum reduction options, we did not estimate the value of these reductions. This was due to lack of analyses on estimating the damages associated with various toxic emissions. Delucchi did not provide these estimates and ARB was limited by resources and time to perform a similar analyses for toxics as they had for $PM_{2.5}$.

To the degree that toxic emissions are reduced due to petroleum reduction options, our analysis underestimates the dollar value associated with those options.

3.4 Valuation of Water Pollution

Reducing California's need for gasoline and diesel fuels could reduce the risk of crude oil and product spills. Spills happen throughout the petroleum distribution system, ranging from spills by ocean-going tanker ships to spills or leaks at service stations. These spills and leaks cause damages to ground water and soils as well as to wildlife, fisheries, and human health. Delucchi made an estimate of these damages for crude oil spills, for leaking underground tanks, and for urban runoff.

Large oil spills draw a lot of public attention around the world and can seriously damage marine ecosystems and losses to fisheries and tourist industries. Delucchi summarized various studies that estimated the costs of oil spills. He pointed out the difficulties facing analysts trying to estimate the marginal cost of oil spills associated with motor vehicle use. It is difficult to estimate, for example, how much oil production will change with a reduction in demand or whose oil production will be affected or which costs are internalized in the price of products sold. He did acknowledge the possible reduced risks and costs as a result of changing legislation that required, for example, the phase-out of all non-double-wall tankers serving U.S. ports by 2010. Delucchi did not address all these issues but reviewed the available data and estimates by others to arrive at his damage estimates for the U.S. of \$0.2 to \$0.5 billion (1991\$). Normalizing by import crude to the U.S. in 1991 (estimated at 2.427 billion barrels) and adjusting to 2001\$ gives a range of 0.25 to 0.64 cents per gallon of crude as shown in Table 3-3 (we further assumed that volume or crude is equal to the volume of refined products as a first approximation).

A similar approach was used for leaking underground tanks. In the late 1980s and early 1990s, the U.S. EPA established technical requirements and financial liability requirements for operators of underground storage tanks. The requirements specified measures to prevent, detect, and clean up leaks. Some liability was covered with a small per-gallon tax on motor fuels so that not all cleanup costs could or would be included in damage estimates. Taking these measures into account, Delucchi estimated that the external cost of leaking underground tanks in the U.S. to be somewhere between \$0.1 and \$0.5 billion. Normalizing by the total gasoline, Jet A, and diesel consumption in 1991 (estimated at 174.4 billion gallons) and adjusting to 2001$ gives a range of 0.075 to 0.37 cents per gallon of refined product.

Urban run off includes leaks or disposal of oil, fuel, coolant, and other chemicals that are discarded from motor vehicles and ultimately end up in our waterways. Delucchi speculated that the cost of this pollution at $0.2 to $0.5 billion. Normalizing by the product used in 1991 and adjusting for 2001$ gives a range of 0.15 to 0.37 cents per gallon of refined product.

Averaging the low and high damages for oil spills, leaking underground tanks, and urban run off gave the $0.009 per gallon of refined product or 0.9 cents per gallon of refined product. To assess the reasonableness of this number, we also performed an independent analysis of the spills throughout the California petroleum infrastructure. The details of this analysis are provided in Appendix F of this report. Without accounting for costs, which may be internalized in the price of gasoline or diesel, our estimates of the costs to clean up petroleum spills was about 4 cents per gallon. Because Delucchi estimated external costs, we would expect our estimates to be higher, which they are. Based on our analyses, we believe Delucchi's estimates are reasonable and, although estimated for the U.S., should also be reasonable for California as the state also imports about 50 percent of its oil (most of this currently comes from Alaska) much like the U.S. as a whole.

3.5 Valuation of Greenhouse Gases

Global climate change poses risks to human health and to terrestrial and aquatic ecosystems. Important economic resources such as agriculture, forestry, fisheries, and water resources may also be affected. Warmer surface temperatures, more severe droughts and floods, and sea level rises could have a wide range of impacts in California. These impacts, along with continuing pressure on our resources caused by population growth, will place considerable pressure on California's existing infrastructure.

Emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorocarbons are the primary manmade emissions that affect global warming. CO_2 is the most prevalent of the GHG, comprising some 84 percent of GHG in California. And, most of these emissions — some 58 percent — are from transportation sources. The transportation sector is, therefore, an important segment of the GHG inventory, and technologies to reduce CO_2 from this sector may have significant benefits to California. Estimating these benefits is the objective of this section.

As in the previous discussions on valuing criteria pollution and fine PM, ideally what we would like is an assessment of the possible effects of increased/decreased emissions of GHG coming from the California transportation sector, thus allowing us to model the change in climate as a result of the change in emissions. The change in climate could then be modeled to determine the effect on human health and a variety of California ecosystems. This process is shown schematically in Figure 3-3. After assessing the possible impacts of climate change, the costs of these impacts could be determined.

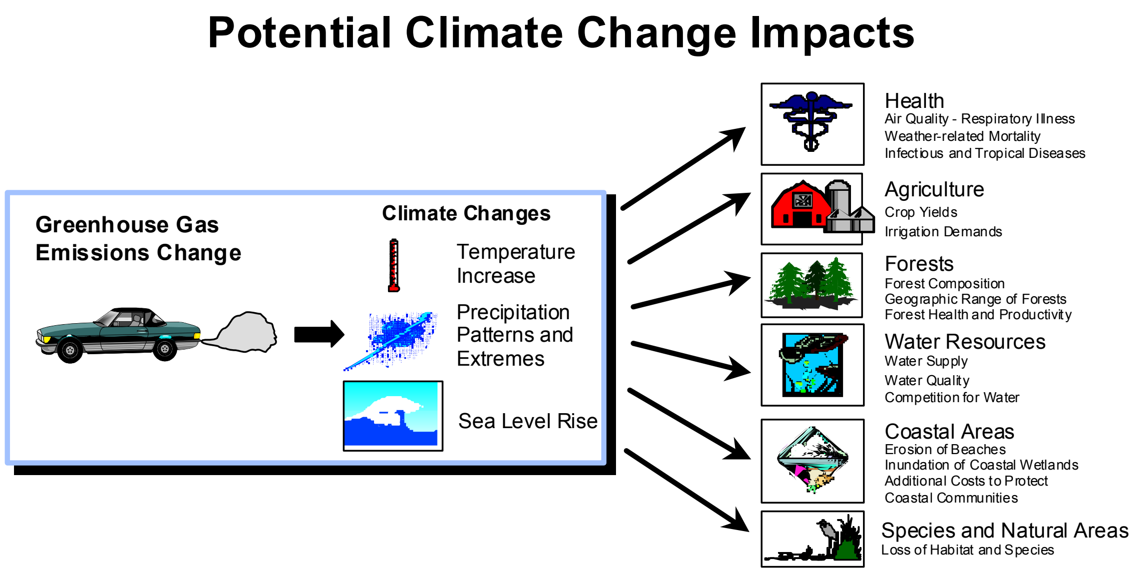


Figure 3-3. Potential Climate Change Impacts

Much work has been completed recently to determine the possible impacts of global warming in California as part of a larger effort to assess the possible impact of climate changes and variability on the United States and its territories. California was designated as one of the regions studied as part of the national assessment. The United States Global Change Research Program and the White House Office of Science and Technology organized this work. The California regional assessment (California Regional Assessment Group) arrived at several key findings, some of which are:

- The climate is changing. Climate change and variability pose significant potential challenges to California's businesses, communities, natural resources, and ecological systems

- Building resilience critical systems is a good strategy and a good investment. We currently have sufficient information to start responding to climate change through cost-effective "no regrets" and "multiple-benefits" strategies.

- California's water systems are over-appropriated, and water management will remain a critically important issue in California. Climate change will provide new and uncertain challenges. Opportunities exist for efficiency improvements in all water-use sectors.

- In California, there is a broad and growing recognition of the need to restore and protect the environment while achieving productivity and profitability in the economy. There are measures we should undertake now, both to hedge our bets, and because they are good investments.

Although this work has identified many of the possible impacts of global climate change, such as the effects on water resources and ecosystems, no estimates were made on the economic cost of these impacts. Thus, there is little information currently available to estimate the possible societal impacts of global warming.

Our approach, then, was to review the literature to determine what analyses have been completed that may provide insights into how to value the benefits of reducing GHGs. The work of both Delucchi and Friedrich and Bickel included estimates of the damages of global warming. Delucchi reviewed several of the major studies performed on global warming, including those by Cline (1992), Nordhaus (1991 and 1993), Ayres and Walters (1991), Fankhauser (1994), Titus (1992), Pearce (1992), Hohmeyer (1996), Energy Commission (1992), Montgomery (1991), and Tol (1995). Delucchi pointed out that there is a considerable range of damages estimated by these analysts, and with some rationale he was able to conclude that a reasonable range of global damages would range from \$1.80 to \$18.15/ton of CO_2 (1991\$).

Friedrich and Bickel summarized modeling performed to estimate the damages of climate change. They used three different models: the Open Framework for Economic Valuation of Climate Change developed by Downing, and two versions of the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) developed by Tol. Using these models, they investigated the marginal costs of CO_2, nitrous oxide (N_2O), and methane emissions in \$/ton. Variables included discount rate and region of aggregation. Because climate change is a long-term issue, discounting can have a significant effect on the net damage estimates. They investigated rates ranging from 0 percent, representative of not discounting the future value of human health and the earth's resources, to 3 percent, indicative of economic growth where people are richer in the future and the dollar has greater relative value now than in the future. They also aggregated the results of the model to include only European Union impacts, EU plus regional impacts, World impacts, and an additional EU plus regional case. The EU case used economic valuation consistent with the EU. The EU plus regional used EU valuations for the EU and regional values for other regions. The world case used globally averaged valuations, and the final case used EU valuations for both the EU and regional analyses. Not unexpectedly, increasing the discount rate lowers the damage estimates, as future damages are valued less than today's. Damage costs per ton of GHG increased with the size of aggregation or with the assumed damage valuation. Their recommendation for the marginal costs of CO_2 is \$1.27/ton to \$3.72/ton. However, they caution that this range should not be viewed as final estimates but more as work in progress, as the impacts covered by the models are only a fraction of all climate change impacts and their concern on how the health and nature impacts are valued in the models.

Due to their assessment of the modeling uncertainties, Friedrich and Bickel recommended that analysts use values of \$17.24/ton in their sensitivity analyses. This value was recommended based on uncertainties in the models and justified on the basis of using avoidance or control costs as a "shadow" value. They observed that the avoidance costs and control costs are considerably higher than the values estimated with the models. They provided several examples. They referenced one estimate of the marginal avoidance costs for Germany to reach the Kyoto target at \$17.24 per ton of CO_2 equivalent. Another estimated the marginal cost for CO_2 abatement for meeting the Kyoto targets in Belgium at 25 Euros per ton of CO_2 (\$25/ton). Friedrich and Bickel suggest that it is possible the current modeling does not capture all the impacts or all the costs, and the higher avoidance costs are a reflection of this uncertainty.

We also performed an independent assessment of estimating climate change damages. Our approach was to review the literature to determine what others have quantified damages at and then to assess how to normalize these damages. To this end we used Kolstad and Toman's (Kolstad 2001) work because they provide a good overview of the various studies on estimating global climate change damages. Table 3-6, taken from this reference, shows the range of damage estimates from five different analysts for the U.S. for a doubling of CO_2. What is immediately obvious from this table is that the details of each analysis vary greatly, but the bottom-line damage estimates are about the same at 1 to 2 percent of GDP.

Table 3-6. U.S. Climate Change Impacts from Doubling CO_2 Emissions

Sector	Nordhaus (1991) 3°C	Cline (1992) 3°C	Fankhauser (1994) 2.5 °C	Tol (1995) 2.5°C	Titus (1992) 4°C
Billions of 1990 U.S. $					
Market impacts:					
Agriculture	-1.1	-17.5	-8.4	-10	-1.2
Energy	-1.1	-9.9	-7.9	—	-5.6
Sea level	-12.2	-7	-9	-8.5	-5.7
Timber	—	-3.3	-7	—	-43.6
Water	—	-7	-15.6	—	-11.4
Total Market	**-14.4**	**-44.7**	**-41.6**	**-18.5**	**-67.5**
Nonmarket impacts:					
Human life	—	-5.8	-11.4	-37.4	-9.4
Migration	—	-5	-6	-1	—
Extreme events	—	-8	-2	-3	—
Human amenity	—	—	—	-12	—
Recreation	—	-1.7	—	—	—
Species loss	—	-4	-8.4	-5	—
Urban infrastructure	—	-1	—	—	—
Air pollution	—	-3.5	-7.3	—	-27.2
Water quality	—	—	—	—	-32.6
Mobile Air Conditioning	—	—	—	—	-2.5
Total Nonmarket	**-41.1**	**-16.4**	**-27.9**	**-55.7**	**-71.7**
TOTAL	**-55.5**	**-61.1**	**-69.5**	**-74.2**	**-139.2**
% of 1990 GDP	-1	-1.1	-1.3	-1.5	-2.5

If we assume that world climate damages scale similarly to U.S. damages, we can estimate world damages based on the results presented in Table 3-6. World damages for climate change are estimated at 1 to 2 percent of world GDP. Then, knowing the world inventory of GHGs, we can estimate the value in terms of $ damage/ton. Table 3-7 shows our estimates of California, U.S., and World gross product for 2001 in 2001$.

Combining the results of Tables 3-7 and 3-8 gives the results indicated in the equation below. Table 3-8 breaks downs one estimate of 2000 world greenhouse gases for CO_2, CH_4, and N_2O. At a 1 percent damage estimate the value of CO_2 equivalent damages is about $10/ton. At 2 percent damage estimate the value of CO_2 equivalent damage increases to about $20/ton.

Table 3-7. Estimates of Gross Product for Various Regions

Gross Product	Billions of 2001 U.S. $$[a]
California	1,169[a]
U.S. GDP	10,510[b]
World	38,202[c]

[a]$1999 scale up to $2001; CPI of 0.941.
[b]EIA International Energy Database, 4/02, Table B2.
[c]World Gross Domestic Product at Market Exchange Rates, 1980-2000. Scaled from 1995 to 2000 w/CPI of 0.861.

Table 3-8. Estimate of Total World CO_2 Equivalent Greenhouse Gas Emissions

Manmade Sources[a]		GWP (100 yr)	Million tons CO_2 equiv/yr
CO_2	6,300.00 Million metric tons C/yr		25,456.20
CH_4	359.00 Million metric tons CH_4/yr	23	9,099.21
N_2O	6.90 Million metric tons N_2O/yr	296	2,250.72
Total Emissions of GHG			36,806.14

[a] Table 2 Global Natural and Anthropogenic Sources and Absorption of Greenhouse Gases from Emissions of Greenhouse Gases in U.S. 2000, DOE/EIA-0573(2000).

$$\begin{array}{c}\textit{Value of } CO_2 \\ (\textit{for Doubling of } CO_2 \textit{ Emissions})\end{array} = \frac{\textit{Estimate of \$ Damages}}{\textit{Total World Inventory of } CO_2 \textit{ Equivalent Emissions}}$$

1 percent = 10.38 2001 $/ton CO_2 Equivalent

2 percent = 20.76 2001 $/ton CO_2 Equivalent

Table 3-9 compares the estimates by Delucchi, Freidrich and Bickel, and the above analyses. The National Academy of Sciences Fuel Economy report (NAS) quotes the range in climate change estimates from $3 to more than $100/ton of carbon. They used $50 per ton as an estimate of the environmental externality of additional carbon emissions. They recognized that this value was larger than that referenced in the literature. $50 per ton carbon translates to $16.50 per ton CO_2 equivalent, midway between our estimate using the percent damages methodology. This table also shows the results for Delucchi and Freidrich and Bickel if we scale their regional results to world gross product. Interestingly, the results all seem to converge when viewed on a world scale. The range is higher for the estimates of Friedrich and Bickel probably due to the broad range of estimates they provided.

Table 3-9. Comparison of Damage Costs of Climate Change 2001$/ton of CO_2 Equivalent

Source	Region	*Low*	*High*	Scaled to World	
				Low	*High*
Delucchi	U.S.	0.43	7.17	1.56	26.04
Friedrich and Bickel	EU	0.09	14.88	0.29	46.89
NAS	World	0.82	27.27		
TIAX Estimate	World	10.38	20.76		

Based on these results, we selected a value of $15 per ton of CO_2 equivalent emissions as our estimate of the damages associated with climate change. This seems roughly consistent with the estimates of other analysts if it is assumed that climate change is viewed as a world issue and not confined to a regional basis such as California, or the U.S. or the EU. In fact, the argument here is that decision-makers need to view climate change as a global problem unlike other forms of air pollution, which are highly regionalized. Emissions of GHGs affect climate on a world basis and not on a local basis.

Friedrich and Bickel and Delucchi also pointed out the differences in valuing climate change damages depending on the perspective of the decision maker. Delucchi argues that regional climate change damages should be scaled by the economic output of the region. So for the U.S., he scaled world damages by the ratio of U.S. GDP to world gross product and by analogy would scale world damages to California damages by the ratio of California GDP to world gross product. It less clear how this was handled in the modeling presented by Friedrich and Bickel and they seemed to have applied both model approach and a scaled approach for their world view alternatives. This could be one reason when we scale their high estimates we get a much higher estimate than Delucchi, NAS, or our estimate.

3.6 External Cost of Petroleum Dependency

Certain costs related to U.S. petroleum dependence are considered external[11] because they are borne by all citizens in the country, but are not reflected in the market price of crude oil. The external costs that have been identified in the literature fall into two broad categories: military costs and economic costs. Military costs include defense expenditures by the U.S. that can be attributed to securing Middle East crude oil supplies and expenditures for the Strategic Petroleum Reserve (SPR). Economic costs include monopoly rent transfers from U.S. consumers of crude oil to foreign oil producers, long-run reductions in U.S. GDP attributable to OPEC's ability to raise crude oil prices above the competitive crude oil price, and short-term macroeconomic effects of crude oil price episodes.

In this analysis, an estimate of the external costs of petroleum dependence was derived from and based upon a review of recent empirical work in this area. This estimate was then converted to a cost per gallon of gasoline or diesel fuel and multiplied by the amount of gallons reduced to give the benefit of reduced external petroleum dependency costs for each option evaluated.

Table 3-10 shows the results of a literature review on the costs of petroleum dependency. Analysts have estimated these costs as ranging from near zero to $0.31 per gallon of gasoline. The most exhaustive studies are probably those by Delucchi (2000) and Leiby et al. (1997), and their two ranges are roughly comparable. We selected a value of $0.12 per gallon of refined product to represent the external costs of petroleum dependency. This is the midpoint of the range given by Leiby et al and is consistent with the recent NAS report on fuel economy.

Table 3-10. Comparison of the Estimated Costs of Petroleum Dependency

Study	Estimate per Gallon Gasoline
Energy Commission (1994)	$0.31
Behrens, et al (1992)	$0.105-$0.30
Delucchi (1997)	$0.005-$0.30
National Academy of Sciences (2002)	$0.12
Ketchen and Komanoff (1992)	$0.334
Mackenzie et al (1992)	$0.253
Leiby et al (1997)	$0.0-$0.24

The estimated costs of $0.12 per gallon is a U.S. estimate and represents the positive impact on the nation as a whole given a reduction in gasoline or diesel use of 1 gallon. In cases where fuel efficiency improves, the application of energy security costs per gallon is straightforward. However, in the case of fuel substitution, energy security benefits from reduced petroleum use may be reduced if the new fuel also comes with external costs. No account of this effect was considered in our analyses.

[11] It should be noted that there is no universal agreement in the literature about which costs should be considered external.

4. DENB and External Cost Reductions Associated with Petroleum Reduction Options

The economic value of emission reductions — previously defined as the direct environmental net benefit (DENB) — is determined in this report to complement the DNNB analysis presented in the Task 3 Report. This section quantifies the DENB from marginal emission and ground and water impact reductions. This section also quantifies the impacts on the external costs of petroleum dependency (ECPD) associated with a reduction in petroleum use.

The DENB was calculated for each of the petroleum reduction options based upon its projected criteria pollutant, GHG, and ground and water impact reduction (Toxics were not included in the DEN for reasons discussed in Section 3). The air emission and ground and water impact reductions determined in Section 2 were monetized for each option based on the valuations, listed in 2001$/ton or 2001$/gallon, shown previously in Table 3-3. The DENB is determined for each option by combining valuations and annual reductions. See Section 1.1.2 for a description of the DENB calculation procedure.

The DENB for a given option was calculated for each year that the option is in use between 2002 and 2030, providing a stream of benefits over this period. The DENB for a given year was discounted at 5 percent annually and expressed in 2001 dollars. This accounting allows each option to be evaluated for a specific year and over a given time period.

As noted in Section 1.1.2, the 5-percent annual discount represents the loss in opportunity for achieving present-day air emissions and ground and water impact reductions and, hence, the loss in value of the associated benefits. Smaller discount factors would produce a larger DENB for each of the petroleum reduction options. In order to consider the impact of a lower annual discount rate, the DENB for each option was also calculated using the lower bound of 0 percent annual discount; these results are presented in Appendix H.

The reduction in ECPD associated with a given petroleum reduction option is calculated from the petroleum displacement for that option, as described in Section 1.2. As with the DENB analysis, the ECPD reduction in a given year was discounted at 5 percent annually and expressed in 2001 dollars.

4.1 Group 1 — Improved Fuel Economy and Other Fuel Efficiency Options

Petroleum reduction through improved fuel efficiency options were evaluated in terms of the DENB and ECPD associated with gasoline and diesel demand reduction. As indicated in Section 2.3, the Improved Fuel Economy (Group 1A) options assume gasoline reductions without a change in VMT. For this reason, the same emission factors are used for all Improved Fuel Economy options. Because there is no VMT change assumed, the emissions reduction and the DENB scale directly with avoided gasoline consumption. The Other Fuel Efficiency (Group 1B through 1E) options also assume gasoline or diesel reduction without a change in VMT, and thus their emissions also scale directly with avoided fuel consumption.

Figure 4-1 shows the DENB for Improved Fuel Economy options in 2002-2030, indicating the individual contributions of GHG, criteria pollutant, and ground and water impact ("Spills") reduction. For every Improved Fuel Economy option, GHG emissions provide the largest contribution to the DENB, comprising 91 percent of the DENB in the 2002-2030 time period. Although the valuation for GHGs was small compared to criteria pollutants — \$15/CO_2 equivalent ton compared to about \$90,000/ton NO_x or \$6,000/ton NMOG — the total GHG benefits for each option was 5 to 6 orders of magnitude larger than the most significant criteria pollutant reduction. The criteria pollutants and spills contributions to DENB were 4.2 and 4.5 percent, respectively.

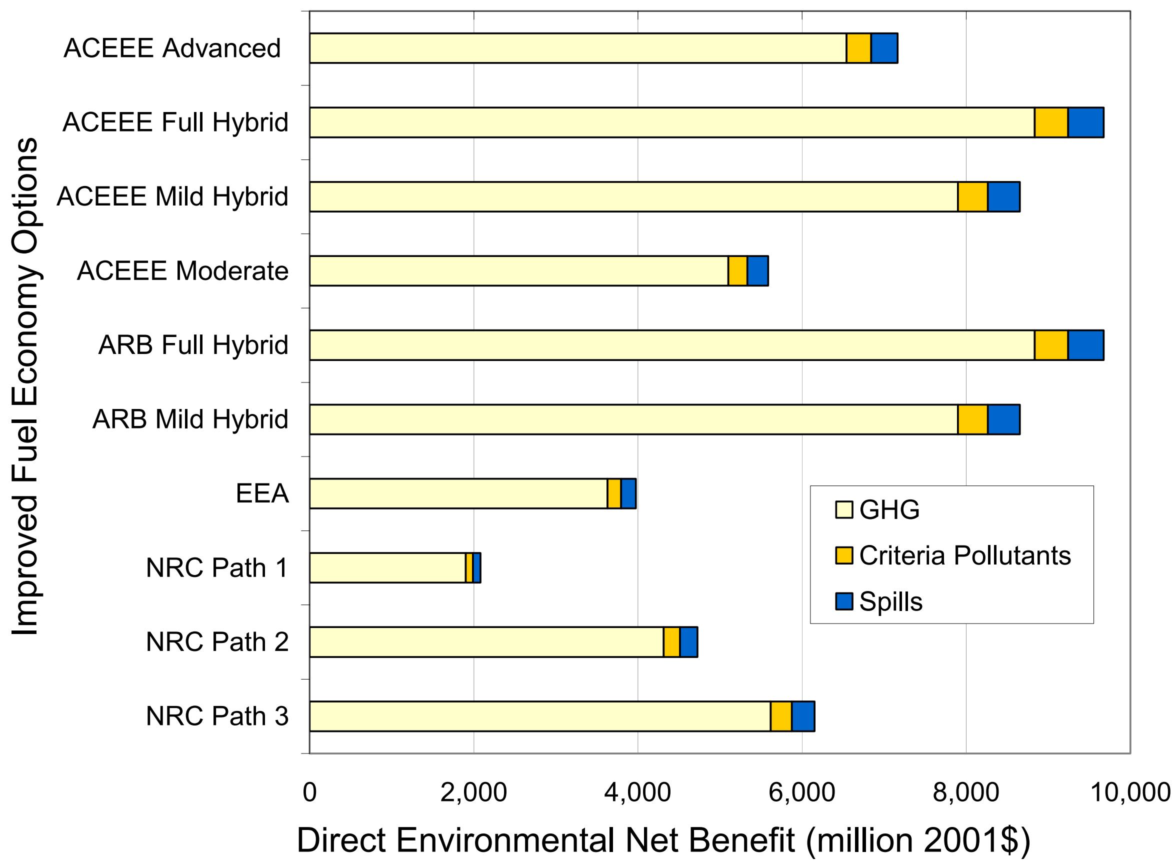


Figure 4-1. Detailed DENB for Improved Fuel Economy Options (Group 1A) in 2002-2030

As expected, the most fuel-efficient Improved Fuel Economy options — the full and mild hybrid options — provide the greatest DENB, ranging from 8.6 to 10 billion 2001\$ during the 2002-2030 timeframe. The Advanced, Moderate, and NRC Path 3 options provide the next largest DENB (5.6 to 7.2 billion 2001\$) for 2002-2030, followed by the EEA and the NRC Path 1 and 2 options (2.1 to 4.7 billion 2001\$).

A range of gasoline prices — as provided in the Task 3 Report — was considered for each of the Improved Fuel Economy petroleum reduction options. The DENB and ECPD were calculated over this range of prices for various timeframes, as shown in Tables 4-1 and 4-2.

Table 4-1. DENB Associated with Improved Fuel Economy Options (Group 1A)

Time Period	DENB (million 2001$) [a]									
	ACEEE Advanced	ACEEE Full Hybrid	ACEEE Mild Hybrid	ACEEE Moderate	ARB Full Hybrid	ARB Mild Hybrid	EEA	NRC Path 1	NRC Path 2	NRC Path 3
2002-2010	121 ± 51	163 ± 51	146 ± 51	90 ± 48	163 ± 51	146 ± 51	38[b]	35[c]	80 ± 52	104 ± 51
2002-2020	3,020 ± 210	4,080 ± 190	3,650 ± 200	2,350 ± 210	4,080 ± 190	3,650 ± 200	1,470 ± 250	878 ± 240	1,990 ± 220	2,590 ± 210
2002-2030	7,160 ± 320	9,680 ± 280	8,650 ± 300	5,590 ± 340	9,680 ± 280	8,650 ± 300	3,970 ± 390	2,080 ± 390	4,730 ± 350	6,150 ± 330

[a] For each of the Improved Fuel Economy options considered, the DENB was calculated over a range of gasoline prices for each year from 2002 to 2030, then discounted and summed. The DENB shown was based on an average gasoline price of $1.64/gallon with a range of $1.47/gallon to $1.81/gallon.
[b] Projections for gasoline at $1.47/gallon are not available. The DENB for a gasoline price of $1.81/gallon under this option is 105 million 2001dollars.
[c] Projections for gasoline at $1.47/gallon and $1.81/gallon are not available.

Table 4-2. ECPD Associated with Improved Fuel Economy Options (Group 1A)

Time Period	External Cost Reductions (million 2001$) [a]									
	ACEEE Advanced	ACEEE Full Hybrid	ACEEE Mild Hybrid	ACEEE Moderate	ARB Full Hybrid	ARB Mild Hybrid	EEA	NRC Path 1	NRC Path 2	NRC Path 3
2002-2010	72 ± 31	98 ± 30	87 ± 31	54 ± 29	98 ± 30	87 ± 31	23[b]	21[c]	48 ± 31	62 ± 31
2002-2020	1,800 ± 130	2,400 ± 120	2,100 ± 120	1,400 ± 130	2,400 ± 120	2,100 ± 120	850 ± 150	500 ± 140	1,100 ± 130	1,500 ± 130
2002-2030	4,300 ± 190	5,800 ± 170	5,200 ± 180	3,300 ± 200	5,800 ± 170	5,200 ± 180	2,300 ± 240	1,200 ± 240	2,800 ± 210	3,700 ± 200

[a] The Improved Fuel Economy option's External Cost reductions were calculated over a range of gasoline prices. The External Cost reductions shown were based on a gasoline price of $1.64/gallon, with a range of $1.47/gallon to $1.81/gallon. The External Cost reductions incorporated a 5% annual discount, in the same manner as the 5% discount used in the DENB calculations.
[b] Projections for gasoline at $1.47/gallon are not available. The External Cost reduction for a gasoline price of $1.81/gallon under this option is 63 million 2001dollars.
[c] Projections for gasoline at $1.47/gallon and $1.81/gallon are not available.

Most of the ECPD and DENB contributions occur in the 2011-2030 timeframe, with a larger share generated in the 2021-2030 timeframe. Because all Improved Fuel Economy options are implemented starting in 2003, 40 percent of the DENB is generated in the 2011-2020 timeframe and 58 percent in the 2021-2030 timeframe. Thus, the benefits from these options are most significant in later years, with a larger growth in DENB occurring after 2020.

Because all of the Improved Fuel Economy options involve gasoline displacement with no change in VMT, both the ECPD and the upstream portion of the DENB scale directly with the volume of gasoline displaced. As a result, most of the ECPD contributions also occur in the 2011-2030 timeframe, with the largest share generated in the 2021-2030 timeframe. As with the DENB, for all Improved Fuel Economy options, 40 percent of the ECPD is generated in the 2011-2020 timeframe and 58 percent in the 2021-2030 timeframe. As with DENB, the ECPD under these options is most significant in later years, with larger growth in External Cost reduction occurring after 2020.

The Other Fuel Efficiency Options (Group 1B through 1E) also result in fuel cycle benefits, requiring less fuel for a fixed amount of VMT. Like the Improved Fuel Economy options, global GHG benefits are the largest contributor to DENB for the Group 1B through 1E options, totaling 91 percent of the DENB for the three gasoline-fueled light-duty options and 93 percent for the four diesel-fueled MDV/HDV options (see Figure 4-2). The criteria pollutants and spills each comprised 3 to 5 percent of the DENB for these options.

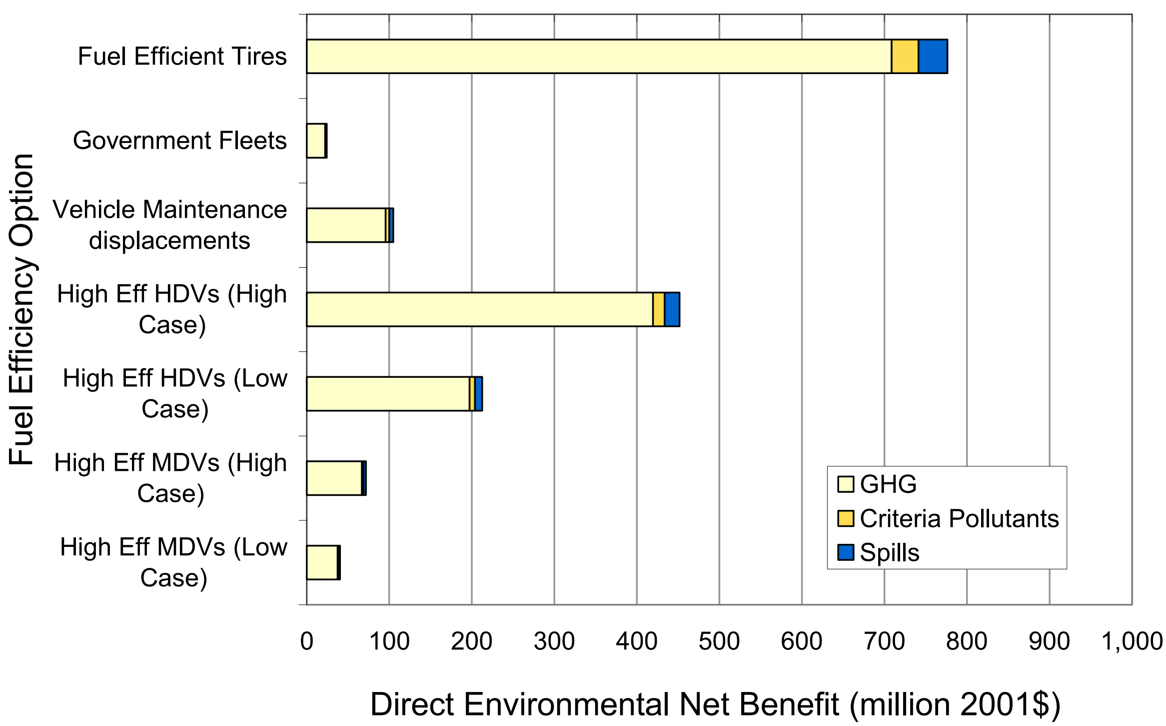


Figure 4-2. Detailed DENB for Other Fuel Efficiency Options (Group 1B through 1E) in 2002-2030

Out of the Group 1B through 1E options, the Fuel Efficient Tires option provides the largest DENB through 2030, totaling almost 800 million 2001$. The next largest DENB for Group 1B through 1E is provided by the High Efficiency HDVs option in the 2002-2030 timeframe, with the high case providing about 460 million 2001$. The same relationships are provided by the ECPD.

Unlike the other options discussed previously, the Fuel Efficient Tires,Government Fleets, and Vehicle Maintenance options generate a larger fraction of their ECPD and DENB in the 2011-2020 time period, with a smaller contribution in later years, as shown in Tables 4-3 and 4-4. For the light-duty Group 1B through 1E options, 40 to 50 percent of the ECPD and DENB is generated in the 2011-2020 timeframe and 30 to 40 percent of the ECPD and DENB were generated in the 2021-2030 timeframe.

In contrast, almost half of the ECPD and DENB for the High Efficiency MDV/HDV options is achieved in 2021-2030, with virtually all of the remainder achieved between 2011 and 2020.

For the heavy-duty Group 1B through 1E options, 36 percent of the ECPD and DENB is generated in the 2011-2020 timeframe and 63 percent of the ECPD and DENB were generated in the 2021-2030 timeframe.

Table 4-3. DENB Associated with Other Fuel Efficiency Options (Group 1B through 1E)

Time Period	DENB (million 2001$)						
	Fuel Efficient Tires	Government Fleets	Vehicle Maintenance Displacements	High Eff. HDVs (High Case)	High Eff. HDVs (Low Case)	High Eff. MDVs (High Case)	High Eff. MDVs (Low Case)
2002-2010	220	3	32	7	3	1	1
2002-2020	540	15	75	170	80	27	15
2002-2030	770	24	100	450	210	72	40

Table 4-4. ECPD Associated with Other Fuel Efficiency Options (Group 1B through 1E)

Time Period	External Cost Reduction (million 2001$)						
	Fuel Efficient Tires	Government Fleets	Vehicle Maintenance Displacements	High Eff. HDVs (High Case)	High Eff. HDVs (Low Case)	High Eff. MDVs (High Case)	High Eff. MDVs (Low Case)
2002-2010	130	2	19	4	2	1	0
2002-2020	320	9	45	100	50	17	10
2002-2030	470	15	63	280	130	45	26

4.2 Group 2 — Fuel Displacement Options

The Fuel Displacement options are based on the use of alternative fuels in place of petroleum fuels. As indicated in Section 2.3, each of the Fuel Displacement options assumes that the baseline conventional fuel is displaced with an alternative fuel or a blend of alternative and conventional fuels. Since the fuel cycle and vehicle emission factors may differ between the fuels used in a given option, some of the Fuel Displacement options incur additional emissions compared to their baseline, even though the baseline and alternative fuel vehicles are assumed to traverse the same VMT.

The detailed DENB results for the Fuel Displacement options in the 2002-2030 timeframe are presented in Figures 4-3 and 4-4. Figure 4-3 presents the detailed results for the light-duty vehicle Fuel Displacement options, and Figure 4-4 presents the detailed results for the heavy-duty vehicle Fuel Displacement options.

GHG emission reductions provide a significant DENB contribution for the light-duty vehicle Fuel Displacement options. However, unlike the Group 1 options, criteria pollutant emission reductions also provide significant contributions to the DENB for some of these options. For example, the Fuel Cell Vehicle option using hydrogen fuel yields a total 2002-2030 DENB of more than $800 million (2001 dollars), 55 percent of which is due to the GHG reductions and 40 percent of which is due to criteria pollutants reductions.

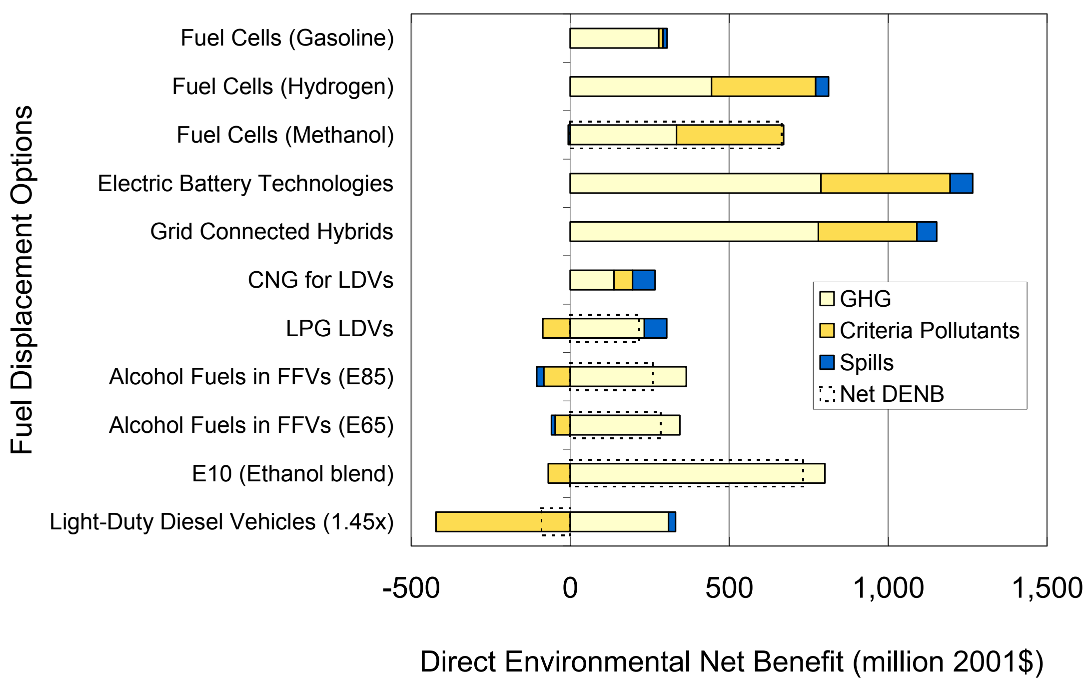


Figure 4-3. Detailed DENB for LDV Fuel Displacement Options (Group 2) in 2002-2030

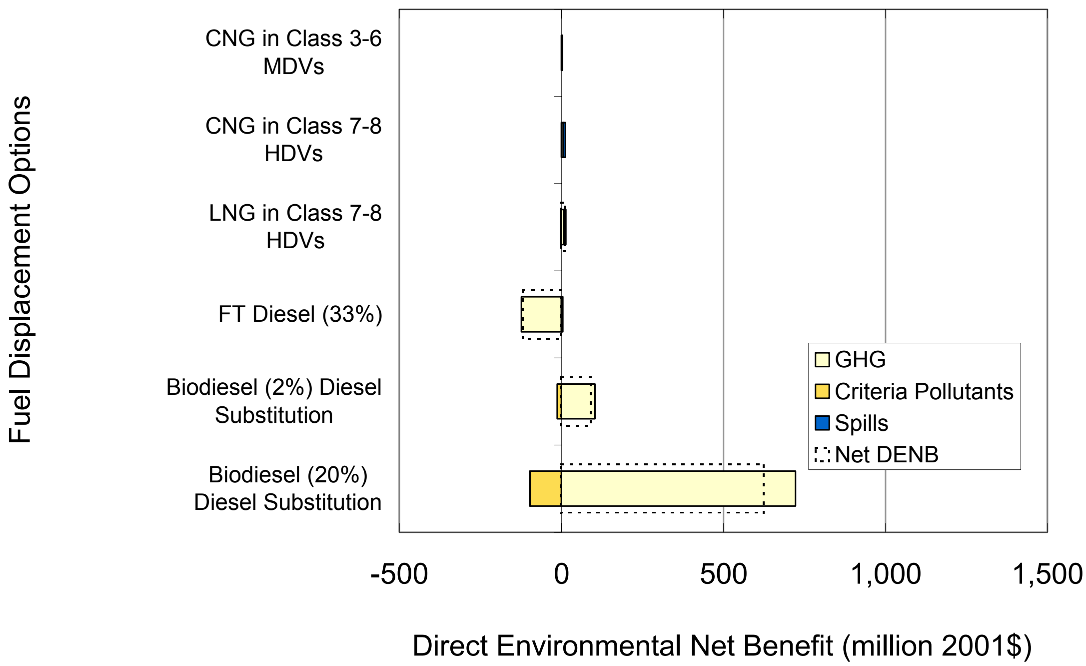


Figure 4-4. Detailed DENB for HDV Fuel Displacement Options (Group 2) in 2002-2030

Some of these options have negative DENB contributions from criteria pollutant or spills increases. For example, the 2002-2030 criteria pollutant DENB contribution for the E10 option is -69 million 2001$, due to a net increase in NO_x emissions. Under options such as E65 and E85, a net increase in liquid fuel consumption implies a net spill volume increase. In turn, this increase in ground and water pollution yields a negative Spills contribution to DENB.

As a result of the negative criteria pollutant DENB contributions, some light-duty Fuel Displacement options offer GHG reductions that are larger than the net DENB. For example, the GHG DENB contribution under the Light-duty Diesel Vehicle option is countered by a negative contribution from increased PM emissions. Although its GHG contribution is comparable to the GHG contribution provided by the methanol FCV option, when combined with the criteria pollutant contribution, the Light-duty Diesel Vehicle option results in a negative DENB.

For the heavy-duty vehicle Fuel Displacement options, GHGs are the largest contributor to DENB. Like the light-duty Fuel Displacement options, some of the heavy-duty options have negative criteria pollutant DENB contributions, such as the biodiesel and LNG options. The FTD33 blend option, however, is unique of all the options considered thus far, in that it has a negative GHG contribution. This option assumes that part of the baseline diesel fuel consumption is replaced with the same volume of FTD, which has a larger GHG fuel cycle emission factor. As indicated in Section 2, because there are no aromatics in FTD, this option provides the largest Toxics emission reductions of all the petroleum reduction options. However, as indicated in Section 3, this analysis does not include a valuation for Toxics, so the potential Toxics DENB contribution is not represented in the net DENB for this or any other petroleum reduction option.

The DENB results for the light-duty Fuel Displacement options are presented in Table 4-5. As shown, EVs, grid connected — or "plug-in" — hybrid vehicles, and hydrogen and methanol FCVs provide the largest DENB for the 2002-2030 timeframe, ranging from about 700 to 1,300 million 2001$. Out of these, the methanol-powered FCVs provide the lowest DENB. Although powered by a fuel cell, the gasoline FCV option provides a DENB of only about 310 million 2001$, about the same level of DENB as the light-duty CNG, LPG, and Ethanol FFV options. E10 provides a DENB in between the Hydrogen and Methanol FCV options, at about 730 million 2001$.

The distribution of ECPD reduction over the 2002-2030 timeframe for the LDV Fuel Displacement options is virtually the same as the distribution of DENB over the same period (see Table 4-6). Except for E10, all options provide most — between 70 and 85 percent — of their ECPD reduction and DENB in the 2021-2030 timeframe, with virtually all of the remainder provided in the 2011-2020 timeframe. For E10, most of the ECPD reduction and DENB are generated in the 2011-2020 timeframe (48 percent), with the remainder spread somewhat evenly between the 2002-2010 and 2021-2030 timeframes (28 and 34 percent, respectively).

The largest ECPD reductions for the LDV Fuel Displacement options are provided by the EVs, grid-connected hybrids, CNG and LPG LDVs, and the E10 options — ranging from about 830 to 980 million 2001$ — with the largest ECPD reduction provided by the E10 option. The second largest range of ECPD reductions are provided by hydrogen and methanol FCVs and the Ethanol FFVs options, ranging from 500 to 700 million 2001$. The smallest ECPD reductions are provided by the gasoline FCV and the Light-duty Diesel Vehicle options, at about 290 million 2001$.

For the ethanol blends (E10, E65, and E85), the Task 3 Report provides petroleum displacement in terms of the gasoline fraction of the baseline fuel avoided minus the gasoline fraction in alternative fuel[12]. Although no other option in this study calculates petroleum displacement in this manner (i.e., treating the ethanol fraction of RFG3 as distinct from the gasoline fraction), the ECPD reduction for these options was based upon the petroleum displacement provided in the Task 3 Report.

[12] The baseline fuel for light-duty vehicle options is RFG3, which was assumed to contain 5.7 percent ethanol for all years in this analysis. See the Task 3 Report for further discussion.

Table 4-5. DENB for LDV Fuel Displacement Options (Group 2) in 2002-2030

Time Period	DENB (million 2001$)										
	Fuel Cells (Gasoline)	Fuel Cells (Hydrogen)	Fuel Cells (Methanol)	Electric Battery Technologies	Grid Connected Hybrids	CNG for LDVs	LPG for LDVs	Alcohol Fuels in FFVs (E85)	Alcohol Fuels in FFVs (E65)	E10 (Ethanol blend)	Light-Duty Diesel Vehicles (1.45x FE)
2002-2010	0.0	0.0	0.0	4.9	4.4	1.0	0.8	1.0	1.0	130	-0.3
2002-2020	47	120	100	370	340	79	64	77	80	480	-21
2002-2030	300	810	660	1,200	1,100	260	220	260	280	730	-70

Table 4-6. ECPD Reduction for LDV Fuel Displacement Options (Group 2) in 2002-2030

Time Period	ECPD Reduction (million 2001$)										
	Fuel Cells (Gasoline)	Fuel Cells (Hydrogen)	Fuel Cells (Methanol)	Electric Battery Technologies	Grid Connected Hybrids	CNG for LDVs	LPG for LDVs	Alcohol Fuels in FFVs (E85)	Alcohol Fuels in FFVs (E65)	E10 (Ethanol blend)	Light-Duty Diesel Vehicles (1.45x FE)
2002-2010	0	0	0	4	3	4	4	3	2	180	1
2002-2020	28	84	84	280	240	280	280	210	149	650	49
2002-2030	180	550	550	940	830	940	940	700	500	980	290

All of the light-duty Fuel Displacement options assume limited market penetration — participation from only a small part of the new vehicle market — except for the E10 option. The E10 option assumes full market penetration, where all gasoline LDVs in California will be using E10. The ECPD reduction and DENB for such full-penetration options are much larger than if they had been designed with limited penetration. For example, although the methanol FCV emission factors are much smaller than the E10 emission factors, the emission benefits of E10 are applied over a much larger fuel consumption volume — between 1 and 4 orders of magnitude larger than that of the methanol FCV option in the 2002-2030 timeframe. As a result, the large fuel displacement compensates for the small per-gallon emission benefits, yielding an E10 DENB that is close to the methanol FCV DENB. Likewise, the large fuel displacement enhances the ECPD reduction, which is based directly upon the volume of displaced petroleum fuel.

The natural-gas-based heavy-duty Fuel Displacement options also assume a limited market penetration. As a result, they provide relatively little ECPD reduction and DENB when compared with the other Fuel Displacement options (see Tables 4-7 and 4-8). Like the E10 option, the diesel blend options for HDVs are full-penetration options, with B20 providing a DENB on par with the E10 and methanol FCV options, at almost 630 million 2001$.

Table 4-7. DENB for HDV Fuel Displacement Options (Group 2) in 2002-2030

Time Period	DENB (million 2001$)					
	CNG in Class 3-6 MDVs	CNG in Class 7-8 HDVs	LNG in Class 7-8 HDVs	FT Diesel (33%)	Biodiesel (2%) Diesel Substitution	Biodiesel (20%) Diesel Substitution
2002-2010	0.1	0.4	0.4	-2.6	16	21
2002-2020	1.6	5.5	5.7	-55	59	330
2002-2030	3.4	12	13	-120	90	620

Table 4-8. ECPD Reduction for HDV Fuel Displacement Options (Group 2) in 2002-2030

Time Period	ECPD Reduction (million 2001$)					
	CNG in Class 3-6 MDVs	CNG in Class 7-8 HDVs	LNG in Class 7-8 HDVs	FT Diesel (33%)	Biodiesel (2%) Diesel Substitution	Biodiesel (20%) Diesel Substitution
2002-2010	0	3	3	27	20	27
2002-2020	5	40	40	560	75	430
2002-2030	12	75	75	1,100	100	690

For the natural gas and FTD33 options, their ECPD reduction and DENB contributions are divided almost evenly in the later years — about 54 percent in 2021-2030 and about 43 percent in the 2011-2020 timeframe. For the biodiesel blend options, greater contributions are made in the 2011-2020 timeframe, especially for the B2 option. Out of all the HDV Fuel Displacement options, only the biodiesel options provide significantly positive DENB when compared with other Fuel Displacement options.

The largest ECPD reductions for the HDV Fuel Displacement options are provided by the B20 and the FTD33 options, providing 690 to 1,100 million 2001$, respectively. The remaining HDV Fuel Displacement options provide very little ECPD reductions, with the largest reductions provided by the B2 option at about 100 million 2001$ over the 2002-2030 timeframe. The natural gas options each provide less than 100 million 2001$ in ECPD reductions.

4.3 Group 3 — Pricing Options

Petroleum reduction through different fuel pricing scenarios was evaluated under the Pricing (Group 3) options. These scenarios alter the cost of driving in order to decrease transportation demand and/or encourage the use of fuel-efficient vehicles. As a result, these options consider changes in both fuel consumption and VMT.

Figure 4-5 shows the various components of DENB for Pricing options in 2002-2030. Like most other petroleum reduction options, the global GHG emission reduction benefits provide the largest contribution to the DENB for the Pricing options, ranging from 67 percent for the Pay-as-you-drive Automobile Insurance option to 98 percent for the Nationwide Feebates option. Criteria pollutants provide the second largest contribution to the DENB, providing 25 to 29 percent of the DENB for the Gasoline Tax, Auto Insurance, VMT Tax, and Registration Fee options. Spills provide less than 5 percent of the DENB for all of the Pricing options.

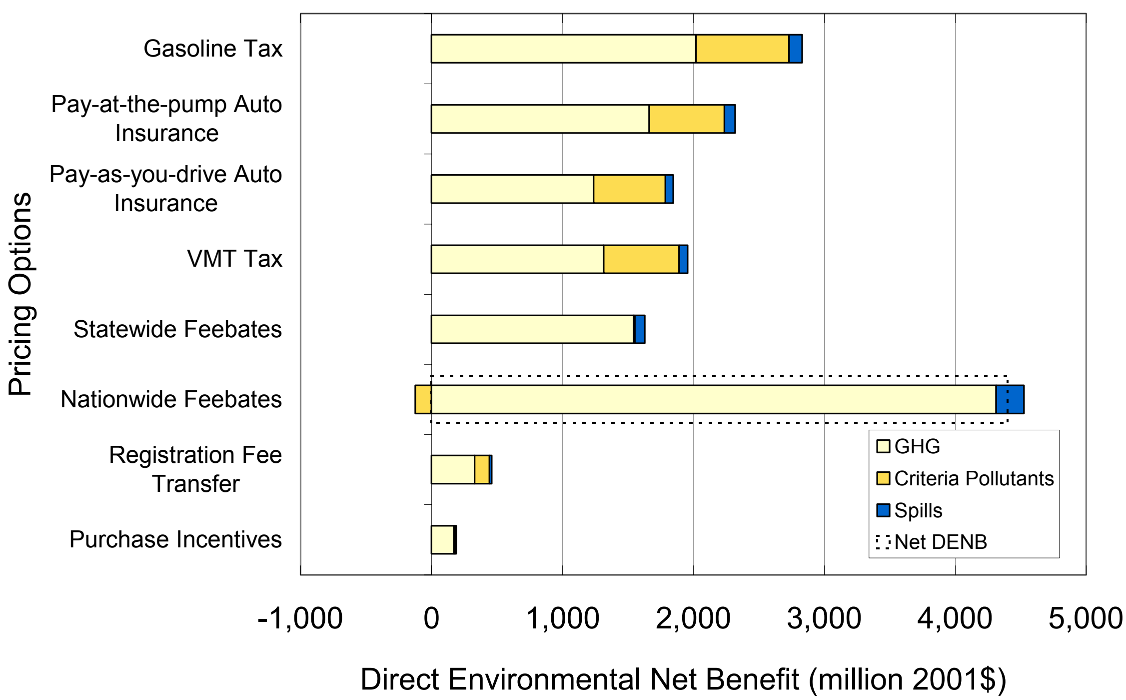


Figure 4-5. Detailed DENB and ECPD for Pricing Options (Group 3) in 2002-2030

The Nationwide Feebates program provides the largest DENB of all the Pricing options — about 4,500 million 2001$ over the 2002-2030 timeframe (see Table 4-9). Most of the other Pricing options provide a DENB of between 1,600 and 2,900 million 2001$. The Pricing options with the lowest DENB are the Registration Fee Transfer and Purchase Incentives options, providing 470 and 200 million 2001$, respectively. The ECPD reductions follow the same trend, with the Nationwide Feebates providing the largest reduction — about 2,800 million 2001$ — and the Registration Fee Transfer and Purchase Incentives options providing the least ECPD reduction (see Table 4-10).

Table 4-9. DENB for Pricing Options (Group 3)

Time Period	DENB (million 2001$)							
	Gasoline Tax	Pay-at-the-Pump Auto Insurance	Pay-as-You-Drive Auto Insurance	VMT Tax	Statewide Feebates	Nationwide Feebates	Registration Fee Transfer	Purchase Incentives
2002-2010	1,064	861	736	783	220	519	172	33
2002-2020	2,121	1,729	1,408	1,494	918	2,369	343	119
2002-2030	2,886	2,365	1,880	1,992	1,673	4,525	469	193

Table 4-10. ECPD Reduction Associated with Pricing Options (Group 3)

Time Period	ECPD Reduction (million 2001$)							
	Gasoline Tax	Pay-at-the-Pump Auto Insurance	Pay-as-You-Drive Auto Insurance	VMT Tax	Statewide Feebates	Nationwide Feebates	Registration Fee Transfer	Purchase Incentives
2002-2010	480	390	319	340	130	320	78	19
2002-2020	970	790	610	650	550	1,500	160	69
2002-2030	1,300	1,100	810	860	1,000	2,800	220	110

Again, most of the ECPD reduction and DENB contribution are provided during the 2002-2020 timeframe. The Pricing options provide about 35 percent of the ECPD reduction and DENB in the 2011-2020 timeframe, with the remainder provided in the early years of the option. Unlike most of the other options previously discussed, these options have relatively significant ECPD reduction and DENB in the early years — the largest DENB falling between 700 and 1,100 million 2001$ in the 2002-2010 timeframe — providing benefits before most options have seen any significant implementation. Overall, the Pricing options provide significant DENB and reduction of ECPD relative to the other petroleum reduction options, especially in the early years of each option.

4.4 Comparison of Benefits Between Petroleum Reduction Options

Overall, the Improved Fuel Efficiency options provide the largest ECPD reductions and DENB of all options over the 2002-2030 timeframe. Only the EEA and NRC Path 1 options from Group 1A are surpassed by one or more largest options from the Pricing options, namely the Nationwide Feebates, the Gasoline Tax, and the Pay-at-the-pump Auto Insurance options. Over the 2002-2030 period, the mid-range Pricing option benefits are a little higher than the best of the Fuel Displacement options — that is, the EVs and grid-connected hybrids. The middle range options in Group 2 are about even with the best of the Other Fuel Efficiency options: Fuel Efficient Tires and the high case of the High Efficiency HDVs. A similar trend is present in the 2002-2020 timeframe.

However, each of these options assumes a particular penetration rate; depending upon real-world support for the option, the benefits that could be achieved in practice may be larger or smaller than what is presented here. Also, some options have an early adoption, providing greater benefits in the early years than those options that ultimately provide the largest benefits over the 2002-2030 timeframe. For example, almost all of the Pricing options have significant benefits in the 2002-2010 timeframe, surpassing the benefits provided by any of the other options during that time period. However, these early benefits are based upon the assumption that these possibly controversial options could be implemented successfully in less than 10 years.

The Fuel Efficient Tires option also provides significant benefits in the 2002-2010 time period. This option provides a DENB of 220 million 2001$ and an ECPD reduction of 130 million 2001$ by 2010. The E10 Fuel Displacement option also provides significant benefits in the 2002-2010 timeframe, totaling 130 million 2001$ in DENB and almost 180 million 2001$ in ECPD reduction by 2010. In comparison, the best of the Fuel options provide only 160 million 2001$ in Economy in ECPD reduction by 2010, almost the same as the E10 option. Again, the early E10 benefits are based on the assumption that the larger volume of ethanol could be implemented statewide in less than 10 years. Unlike the Group 1 options, however, this option doesn't require the purchase of new vehicles for implementation, as it is assumed that the fuel would be used by all on-road gasoline vehicles.

4.5 Possible California Economic Impacts of Petroleum Reduction Strategies

Finally, we also wanted to determine the effects of petroleum reduction strategies on the California economy. Intuitively, reducing the demand for gasoline and diesel should save consumers and businesses money that could be spent in other sectors of the economy. Fuel efficiency options that reduce gasoline consumption would also reduce the demand for refined petroleum products and crude oil. Both these petroleum sectors would therefore be reduced. Reduced gasoline demand would also decrease the price of gasoline and have the additional effects of further reducing the output of the petroleum sectors and making driving cheaper to consumers. Increased consumer driving as a result of lower driving costs could offset these effects.

All these inter-related effects are complicated and typically models are used to sort out the effects that various policies may have on the California economy. The model that was employed was a modified version of the Environmental-Dynamic Revenue Analysis Model (E-DRAM).

This model was built for the ARB and jointly developed by California's Department of Finance. The model has been successfully used to perform dynamic revenue analyses of proposed legislation. E-DRAM is a computable general equilibrium model of the California Economy. It describes the relationship among California producers, California households, California governments, and the rest of the world. For this model the California economy is divided into 93 distinct sectors: 29 industrial sectors, 2 factor sectors (labor and capital), 9 consumer sectors, 7 household sectors, 1 investment sector, 45 government sectors, and one sector representing the rest of the world. The model solves for the prices of goods and services and factors of production that make quantity demanded and supplied equal. Both physical goods and money are conserved.

For examining petroleum dependency issues, E-DRAM was enchanced in three ways. First, petroleum sector data was modified to include current EIA data on the supply/demand of petroleum based fuels. Second, the 1998/1999 base year model was extrapolated out to 2020 and 2050 based on state population, personal income, and industry-specific forecasts. Third, parameters were included to adjust for fuel efficiency and fuel displacement technological changes. These changes are fully documented along with the results of the analyses in Appendix A.

Table 4-11 shows the assumptions used in the modeling. These assumptions are consistent with the baseline modeling described in Section 2. The Energy Commission's forecast methodology uses California Department of Finance data for state personal income and population and then predicts petroleum demand. Consumption and production values were estimated using the forecasted prices for crude and refined products. For this analysis, California refining capacity was allowed to grow from 1999 levels until 2020 at 0.5 percent per year and California crude production was reduced from 2.73 million barrels per year in 1999 to 0.90 million barrels per year in 2020 and no production in 2050. Similarly, Alaskan production was reduced from 3.87 million barrels per year in 1999 to 0.19 million barrels per year in 2020 and no production in 2050. Imports make up the shortfalls in crude oil and refined products.

Table 4-11. Modeling Assumptions for California Economy

Parameter	1998/99	2020	2050
State Personal Income (billions of 2001$)	$892	$2,007	$4,319
Population (millions)	34.7	45.5	68.2
Petroleum Consumption (billions of 2001$)	$28.6	$56.6	$98.9
Production (billions of 2001$)	$32.4	$52.4	$52.5
Net Refined Imports (billion of 2001$)	$-3.8	$4.1	$46.4

Four petroleum reduction strategies were analyzed in 2020 and 2050. Each of the strategies included blending Fischer Tropsch diesel with conventional diesel fuel combined with various light-duty fuel economy strategies. The light-duty options that were combined with the Fisher Tropsch (or Gas to Liquids, GTL) are summarized as follows:

1. EEA, fuel efficiency options phased in over time ultimately providing a light-duty on road fuel economy of 27.7 mpg.

2. ACEEE advanced fuel efficiency options phased in over time and providing a light-duty on road fuel economy of 34.4 mpg.

3. ACEEE moderate fuel efficiency options phased in over time coupled with fuel cell vehicles phased in starting in 2020 to level off gasoline and diesel demand to 2000 levels.

4. ACEEE full hybrid fuel efficiency options phased in over time and providing a light-duty on road fuel economy of 45 mpg.

These strategies were selected to provide the range of costs and benefits shown in Table 4-12. The most aggressive strategy, which includes full hybrids, has costs that exceed benefits in 2020 and 2050. All other strategies have benefits that exceed costs. Most of the costs and most of the benefits were allocated to private consumers with the remaining costs and benefits going to industry.

Table 4-12. Modeling Input Strategies

Strategy	2020 (million 2001$)		2050 (million of 2001$)	
	Costs	Benefits	Costs	Benefits
1. EEA LDV +GTL Blend	2,187	3,264	5,858	14,614
2. ACEEE Advanced+GTL Diesel Blend	4,824	9,284	7,752	19,746
3. ACEEE Moderate+GTL Blend+Fuel Cell Vehicles	7,970	8,269	20,782	26,170
4. ACEEE Full Hybrid+GTL Blend	13,660	12,533	22,054	29,896

The results of the analyses for 2020 are summarized in Table 4-13 for the four strategies considered. Similar results were obtained for 2050 and can be found in Appendix A.

The analysis concludes that the statewide economic impacts are small for any of the four considered strategies. This is not surprising, given that static costs estimates of the most aggressive strategy was $14.4 billion in 2020, a time when gross state product (GSP) was projected to be $3.1 trillion, and $23.3 billion in 2050, when GSP was projected to be $6.6 trillion. The highest static cost estimates are thus only 0.35 to 0.47 percent of projected GSP.

Results for the most modest and aggressive strategies are summarized below as bounding cases. As indicated above, E-DRAM predicts that general equilibrium effects on state output and income are small. Predicted impacts on petroleum refining and crude oil production sectors are much larger, and should be interpreted as worst-case given the E-DRAM's weakness in allocating domestic demand reductions between domestics and imported products. In general, the modeling results show a very slight reduction in state output (within the model's calibration error) and nearly constant SPI. Real personal income remains constant while output falls

Table 4-13. Impact on California Economy of Petroleum Reduction Strategies

2020	BASE MODEL	Strategy 1	Strategy 2	Strategy 3	Strategy 4
CA OUTPUT ($BILLION)	3078.0223	3074.9243	3070.0183	3069.4120	3062.4866
% CHANGE CA OUTPUT	0.10%	-0.10%	-0.26%	-0.28%	-0.50%
CA PERSONAL INCOME ($BILLION)	2009.5373	2009.5213	2010.4295	2006.5412	2001.0251
% CHANGE CA PERS. INC.	0.11%	0.00%	0.04%	-0.15%	-0.42%
LABOR DEMAND (MILLIONS)	18.6605	18.6767	18.7119	18.6841	18.6726
% CHNGE LABOR DEMAND	0.03%	0.09%	0.28%	0.13%	0.06%
PRICE OF CFOOD	1.0001	1.0001	1.0002	1.0013	1.0026
PRICE OF CHOME	1.0000	1.0000	1.0001	1.0008	1.0018
PRICE OF CFUEL	1.0000	0.9687	0.9111	0.9215	0.8818
PRICE OF CFURN	1.0001	1.0001	1.0002	1.0011	1.0022
PRICE OF CCLOTH	1.0001	1.0001	1.0002	1.0011	1.0023
PRICE OF CTRANS	1.0000	1.0072	1.0171	1.0271	1.0513
PRICE OF CMED	1.0001	1.0002	1.0006	1.0020	1.0038
PRICE OF CAMUS	1.0000	1.0001	1.0002	1.0013	1.0027
PRICE OF COTHR	1.0000	1.0000	1.0001	1.0008	1.0017
ENMIN					
OUTPUT ($BILLION)	6.2086	6.0575	5.7836	5.7448	5.6084
% CHANGE OUTPUT	0.08%	-2.43%	-6.84%	-7.47%	-9.67%
IMPORTS ($BILLION)	36.0105	34.8290	32.6693	32.5922	31.8337
% CHANGE IMPORTS	0.07%	-3.28%	-9.28%	-9.49%	-11.60%
EXPORTS ($BILLION)	1.0965	1.1122	1.1419	1.1430	1.1542
% CHANGE EXPORTS	-0.07%	1.43%	4.15%	4.25%	5.27%
PETRO					
OUTPUT ($BILLION)	39.3048	37.6902	34.7300	35.3868	33.5161
% CHANGE OUTPUT	0.07%	-4.11%	-11.64%	-9.97%	-14.73%
IMPORTS ($BILLION)	15.6834	15.5646	15.3455	15.3992	15.2814
% CHANGE IMPORTS	0.01%	-0.76%	-2.15%	-1.81%	-2.56%
EXPORTS ($BILLION)	11.9979	12.0739	12.2159	12.1807	12.2582
% CHANGE EXPORTS	-0.02%	0.63%	1.82%	1.52%	2.17%
ENGIN					
OUTPUT ($BILLION)	40.4675	40.5818	40.6323	40.6730	40.8046
% CHANGE OUTPUT	0.05%	0.28%	0.41%	0.51%	0.83%
IMPORTS ($BILLION)	9.0494	9.0815	9.1111	9.1578	9.2482
% CHANGE IMPORTS	0.02%	0.35%	0.68%	1.20%	2.20%
EXPORTS ($BILLION)	13.8359	13.7822	13.7330	13.6559	13.5091
% CHANGE EXPORTS	-0.03%	-0.39%	-0.74%	-1.30%	-2.36%
CHEMS					
OUTPUT ($BILLION)	30.2836	30.6482	31.3101	32.0653	31.6679
% CHANGE OUTPUT	0.22%	1.20%	3.39%	5.88%	4.57%
IMPORTS ($BILLION)	39.3028	39.2943	39.2798	39.3585	39.4178
% CHANGE IMPORTS	0.01%	-0.02%	-0.06%	0.14%	0.29%
EXPORTS ($BILLION)	2.0905	2.0910	2.0918	2.0872	2.0838
% CHANGE EXPORTS	-0.01%	0.02%	0.06%	-0.16%	-0.32%
FOODS					
OUTPUT ($BILLION)	92.9579	95.1127	99.2793	98.4497	101.3527
% CHANGE OUTPUT	0.14%	2.32%	6.80%	5.91%	9.03%
APPAR					
OUTPUT ($BILLION)	25.9513	26.4969	27.6314	27.1334	27.5086
% CHANGE OUTPUT	0.20%	2.10%	6.47%	4.55%	6.00%
MOTOR					
OUTPUT ($BILLION)	18.2243	18.1613	18.0770	18.0142	17.8553
% CHANGE OUTPUT	0.23%	-0.35%	-0.81%	-1.15%	-2.02%

because of increased consumer purchasing power due to improved fuel efficiency. Labor demand increases in most strategies especially for the 2050 cases.

Strategy 1, which embodies the most modest fuel economy improvements, may cause state gross products (GSP) and state personal income (SPI) to be slightly lower than would otherwise be the case. The model predicts Strategy 1 lowering 2020 GSP by 0.10 percent -- a magnitude within the bounds of model calibration error, and 2050 GSP by 0.17 percent. The strategy's predicted effect on state personal income is essentially zero in 2020 and 0.10 percent (again, a magnitude within the bounds of calibration error) in 2050. Impacts on the directly effected sectors – crude oil producers (ENMIN) and petroleum refiners (PETRO) – are significant compared to the base year. The results indicate crude oil production and petroleum refining dropping by 5.9 and 16.8 percent, respectively. Declines in these sectors -- which are triggered by fuel efficiency gains -- are offset by fuel cost savings being spent in other sectors.

Strategy 4, which embodies the most aggressive change, has a modest impact on GSP and a marginal effect on SPI. The model predicts in this strategy a lower GSP of 0.50 percent in 2020 and 0.46 percent in 2050. The effects on SPI are –0.42 percent in 2020 and -0.46 in 2050. As expected, the predicted impacts of this strategy on energy related sectors are large at least in comparison to the 2020 or 2050 base years (these sectors actually increase compared to the 1998/1999 base year). Crude oil producer's output falls 9.6 percent in 2020 and 12.6 percent in 2050. Petroleum refining sector output also falls to 14.7 percent in 2020 and 32.6 percent in 2050. Again, reduced spending in these sectors is displaced to others.

5. Summary of Economic Benefits

Dependence on imported petroleum products results in a significant impact on the California economy. As California's population grows, the state's reliance on imported sources will continue to rise while in-state refining capacity is limited. Fuel shortages and price impacts have the potential to adversely impact the state's economy, which forces the state to find a solution. State policy makers are analyzing a variety of strategies to reduce California's dependence on petroleum. These strategies will be comprised of options such as improving vehicle fuel economy, using alternative fuels, and reducing miles traveled.

This study, which is Task 1 of the Evaluation of Petroleum Replacement Options, provides an evaluation of the ECPD reduction and DENB of reducing statewide gasoline and diesel consumption. These DENB include air emissions and petroleum spill or ground and water pollution impacts. The extent of reductions in air emissions and ground and water impacts was determined for the petroleum reduction options identified by the California Energy Commission in the Task 3 report. This report also includes an assessment of the impacts of reducing the external costs of gasoline and diesel usage on the state's economy.

Gasoline and diesel consumption result in air emissions and ground and water pollution. The extent of these emissions and spills was determined for various options by quantifying the emissions that correspond to each petroleum displacement option based on changes in the gallons of fuel used and miles driven.

Emissions impacts include fuel cycle and vehicle emissions. Fuel cycle emissions are the result of the production, transportation, and distribution of fuels. Vehicle emissions include those from the exhaust as well as evaporative or fuel system losses. Emissions from the fuel cycle and the vehicle include the criteria pollutants — NO_x, PM, CO, NMOG, and Toxics — as well as GHGs. Both diesel PM and some components of the NMOG are toxic air contaminants.

In order to determine fuel cycle emissions, all of the steps associated with producing and distributing fuels in California were identified. Reducing gasoline and diesel demand in California would result primarily in a reduction in imported products. Consequently, the fuel cycle emissions associated with reduced gasoline and diesel consumption correspond to a reduction in tanker ship and local delivery truck emissions, as well as fugitive NMOG losses from fuel transfers, bulk terminals, and vehicle refueling. These emissions were determined based on emission standards that would be in effect beyond 2010.

For gasoline, diesel, and a variety of alternative fuels, the fuel cycle emissions were determined on a g/gallon (or per-unit fuel) basis. These emission factors were then used to determine the tons per year of emission reduction for each petroleum displacement option.

The emissions from vehicles were also determined. A baseline gasoline PZEV was assumed for LDVs and emission rates were based on in-use emission factors determined by the ARB. As the PZEV standard represents a very low level of emissions, diesel, and alternative-fueled vehicles were assumed to emit at the standard with the exception of technologies with inherently zero emissions, such as electric or fuel cell vehicles. Emission rates were also determined for HDVs and, again, the most stringent standards (EPA/ARB 2007 heavy-duty engine standards) were assumed.

In summary, reducing a gallon of gasoline consumption results in the reduction of approximately 1.1 g of criteria pollutants and 11 kg of GHG emissions (from both the vehicle and fuel cycle). Additionally, reducing a mile of driving results in the reduction of approximately 0.03 g of criteria pollutants.

The values of monetary damages per ton of pollutant were then determined. These valuations were estimated using peer-reviewed EPA and ARB methodologies for societal cost-benefit analyses, and included an assessment of exposure, damages or incidences associated with exposure, and an assessment of society's willingness to pay for these damages. The results of these valuations showed that fine PM ($PM_{2.5}$) causes the largest damage per ton, but these emissions are "relatively" controlled through very stringent vehicle standards especially for diesel LDVs and HDVs.

The value of monetary damages per ton of GHG emissions (CO_2 equivalent) were found to dominate net environmental benefits in most options considered. This is not surprising considering that no controls on GHG emissions (or improvements in baseline fuel economy) were assumed, and the strictest possible controls were envisioned to control criteria and toxic emissions from vehicles. Also, unlike criteria or toxic emissions, which impact local populations, climate change is a global issue, meaning that emission reductions may affect other regions of the world more than California. Decision makers need to decide on their willingness to accept how broad the climate change problem is. World damages were estimated at $15/ton of CO_2 equivalent, but arguments could be made that U.S. or California damages scale down by economic output which would reduce damages to $3.75/ton CO_2 for U.S. and $0.50/ton CO_2 for California. Conversely, damages — especially health-related — may not be proportional to economic output. Thus, there is much uncertainty over the absolute valuation of climate change, and, consequently, still more work is needed in this area.

Ground and water pollution impacts were also analyzed on a per-gallon of gasoline basis. Spill rates were identified from a variety of sources including marine vessels, underground tanks, and pipelines. The cost of reducing spills (beyond those costs included in the price of gasoline) was used to value their impacts as large fuel spills are generally cleaned up as required by law.

Overall, the largest ECPD reduction and DENB were provided by the Improved Fuel Economy options over the time period considered in this study (2002-2030), with the Full Hybrid options providing an average DENB of almost 10 billion 2001$ and an ECPD reduction of almost 6 billion 2001$. Significant benefits in the early years can be achieved by the Pricing options — which do not directly require a certain technology or product to be available in the marketplace — the best of which could provide a DENB of about 1 billion 2001$ by 2010, as well the Fuel Efficient Tires and E10 options, which could provide a DENB of 220 and 130 million 2001$, respectively, by 2010.

Finally, many comments were received on early versions of this report. A summary of many of the comments and our response to these comments are provided in Appendix I. Many of the comments received were incorporated into this version of the report.

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